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The Fringe of the Wood

THE YEAR 1958 will probably rank as one of the most difficult periods for commercial organizations concerned with major developments in nuclear energy. No power stations were ordered by the U.K. generating authorities, yet design and contract costs have materially increased compared with the previous year. Construction of the four U.K. stations already in hand has proceeded, for the most part, according to schedule and on some sites is ahead of programme, but the civil engineers have had to combat unusually poor weather conditions, and the problems associated with heavy plate fabrication on site have proved, in some cases, to be more intractable than originally anticipated.

More important, however, have been the design modifications and the constructional programme adjustments made necessary by our advanced knowledge of graphite behaviour and core physics. Research into the mechanism of Wigner energy storage has resulted in the requirement that graphite temperatures within the power reactors should be so increased that periodic energy release is not necessary. This has been associated with a demand for increased instrumentation. It has also become clear that zoned control of large reactors is desirable, as against the unified control across the core previously adopted. In addition, has come the military demand that provision should be made for the extraction of fuel elements at an earlier stage of burn-up than was originally planned. All these have added complexity to the plant and, although incorporation in new designs presents comparatively few difficulties, modification to current designs inevitably presents major headaches.

Ahead

Next year will see two U.K. contracts placed, Trawsfynydd and Dungeness (subject to approval), and two groups at least will then be in a more comfortable position for phasing development and construction work. For the other groups this will be small consolation and a protracted period of financial uncertainty can only be avoided if the faith of this country in nuclear generation is kept constant, and all possible assistance given to export efforts. We are not out of the wood yet and Geneva made it clear that the export market is no band-wagon just waiting to be stepped on, but a number of possible contracts are in the offing and the materialization of only two or three of these would do much to bring stability to the power reactor field. One major landmark of 1958 was, of course, the concluding of the world's first export power-reactor contract agreement with a British company and it is to be hoped that this will be the forerunner of many similar projects. Nevertheless, SENN decided in favour of U.S. General Electric and, whilst there may have been contributory forces operating in favour of a second reactor type in Italy, the fact remains that the decision was not made in Britain's favour.

SENN Lessons

There are a number of lessons to be learnt from the SENN tender examination. First and foremost it is that the BWR is a very real contender in the world market. There has been a great tendency to place unquestioning reliance in the bold and broad phrases so often quoted that Britain is ahead in the power reactor field; that there is no country with comparable operating or construction experience; that natural uranium must be cheaper and strategically safer. There is more than a grain of truth in these assertions, but they are not the whole story and, particularly in high interest areas, the BWR is, to say the least, on paper highly competitive. It is idle also to complain that the economics of this system are based on unreal enriched fuel prices and burn-ups that cannot be achieved. Whether U.S. U^{235} prices are real or not is immaterial; they are established and operating and only this matters. Also, scepticism about possible burn-up is largely based on wishful thinking; it will be, indeed, surprising if 10,000 MWd/tonne does not become a commonplace in the relatively near future.

It is of prime importance, therefore, that overseas bids by U.K. companies should be backed up by an imaginative and liberal fuel policy. The responsibility for this rests fairly and squarely on the shoulders of the U.K.A.E.A. The Authority has been progressing slowly in the direction of a more positive approach towards guaranteeing burn-up, but if it is to remain a commercial undertaking, it must be prepared to take reasonable commercial risks and back its forecasts to the hilt—not part-way. Also it must take its full share of promotional work, including, if necessary, financing of the first charge. Furthermore, its fuel element prices at present are too

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high. This can readily be proved by offering commercial organizations the opportunity of undertaking fuel element production; let competition exert an influence on the price, the Generating Board here will certainly not object. Another commercial practice that the Authority should consider is the examination of hypothetical cases. Sheltering behind ministerial tradition and refusing to do this, is hardly in keeping with the money-making organization that has been set up.

An Appeal for Candour

Another lesson we can learn from our efforts in Italy and also Japan, is the damage that lack of candour can do—and we are not trying to suggest that some commercial security is not vital to a commercial enterprise. Similarly, presumably, no one in the U.K. would attempt to claim omniscience in reactor technology, but this is the impression that we regularly try and give to the outside world. We have also been guilty in the past of underrating the capacity and quality of overseas engineers, whether these be competitors or customers. It is a mistake, too, to snipe at competitors as this has a nasty habit of rebounding. For example, the perfectly straightforward and in no way catastrophic positive temperature coefficient story has inevitably sounded thin when placed against the background of safety propaganda put up a couple of years ago.

We have a reputation for honesty when discussing our achievements and we should ensure that not only is this maintained but that we are equally candid when discussing our mistakes or miscalculations. The grapevine is not the proper vehicle for major and perhaps, on face-value, disturbing disclosures, neither are odd mentions in lectures given in overseas countries. Classification of information, based solely on the reason that it would not bring credit to the establishment responsible is wrong, both morally and politically.

Looking ahead, we have every reason to be confident about the development programme that is now under way. It is reasonably flexible and is based on as broad a front as this country can accommodate. An encouraging sign also is that greater degree of co-ordination within the Authority and between the major groups on the research and development side, a matter not above criticism in the past. 1959 should prove to be a most interesting year and should see the scope of the "second stage" within the United Kingdom clearly defined.

Marine Insurance

SPEAKING at a meeting of the Insurance Institute of London on December 1, Mr. A. B. Stewart of Lloyd's gave a forthright account of his views on the particular problems of marine insurance, arising from the inevitable widespread application of nuclear propulsion, and the manner in which these should be solved. Mr. Stewart took pains to emphasize that this was his personal evaluation but, quite apart from his long association with Lloyd's, he has also been chairman of an international study group considering this question and his opinions must carry considerable weight.

In 1953 the general opinion on marine insurance was that the risk was so catastrophic as to be beyond the industry; the emphasis was not on whether it should be excluded, but how. This view has not entirely disappeared but is by no means so widely held as it was five years ago.

Marine insurance is somewhat different from non-marine, involving as it does in the main, ships and goods in transit. Many of the risks will, of course, be the same with a nuclear ship as with a conventional ship but some could well be smaller in the nuclear case, as for example the explosion risk, which should be considerably less than with fossil-fired ships and so small as to be unimportant. Similarly the fire risk should be smaller. A special problem which must, however, be considered, is the damage which might result following a nuclear explosion which scattered radioactive material over a large area. The Windscale incident, far from alarming insurers, should do much to convince them that fall-out risks are on quite a modest scale, compared with many of the risks the insurance industry at present takes in its stride.

The crux of the problem concerned capacity, the maximum risk that could be covered without endangering the stability of the market. Taking into consideration some of the major losses that insurers have covered, such as the San Francisco earthquake, and the major risks that are currently covered, such as insurance of the "Queens," the maximum risk associated with a nuclear-propelled vessel would not be large, and far from introducing clauses excluding certain risks, the marine market could well consider the inclusion of risks which are at present excluded from the standard policy. The market could not only give coverage and liability for reactor breakdowns whatever the cause but also third-party liability up to, say, £5 million. Unlike the non-marine insurance, there was no need of pools to handle these risks, and the business could be channelled through the brokers in the normal manner.

Although perhaps more adventurous than some, Mr. Stewart has made a very careful analysis of the dangers of nuclear propulsion and the risks involved. To those who find the assurances of the scientists somewhat unconvincing, feeling that a vested interest has perhaps warped their judgment, Mr. Stewart's confidence should bring considerable comfort. The shipping industry should also welcome the assurance that, when the time comes for nuclear vessels to be launched, the problem of insurance which could be a major stumbling block, should be largely resolved and, should Mr. Stewart have his way, and we hope he will, in a simple and straightforward manner. Let us hope that international law governing the passage of nuclear-propelled ships in harbours, as well as at sea, will be tackled with this same realistic approach.

DIGEST...

Surveying Significant News

Euratom-U.K. Agreement Delayed

The Euratom-U.K. agreement has not yet been signed, and it now seems unlikely that this will occur before late January. Members of the Commission of Euratom arrived in London recently for discussions with the A.E.A. and the Foreign Office, but it is understood that the text of one of the Articles is unacceptable in its present form, and the Foreign Office has requested that this be reconsidered. Negotiations are still taking place.

Nuclear Supply Agency, Terms of Reference

The Nuclear Supply Agency set up under Euratom will have right of option on all ores, source materials and special fissionable materials used in the community countries and an exclusive right of concluding contracts relating to such supplies coming from inside or from outside. The Agency will be financially independent and will operate as a non-profit-making organization according to commercial rules. Its function will be as an intermediary between supplier and customer, except in the case of shortage. A consultative committee is to be set up representing suppliers and consumers.

A.E.C. Modifies Uranium Purchasing Agreements

In May, 1956, the A.E.C. announced that it would guarantee the purchase of U_3O_8 in concentrates over the period April, 1962-Dec., 1966. The Commission now announces that it will carry out these commitments with respect to ore reserves developed prior to this date and purchases will be at the previously established price of $8/lb. With respect to new ore reserves developed after this date, the Commission will make contracts according to prevailing demands. The provision is aimed at curtailing over-production while still maintaining a regular supply over the next 10 years.

Increased Activity in Japan

Following Sir John Cockcroft's visit to Japan, during which he did much to reassure Japanese scientists and engineers on the practicability of building Calder Hall type plants in that country, there are suggestions that the requirements for nuclear plant of the Calder type will not now be confined to one reactor. G.E.C. has announced the concluding of a manufacturing agreement with the Fuji Electric Co. in anticipation of an order from the Japanese Atomic Power Generating Co. The first contract may not be placed with a British consortium until April, but it is believed that this will be followed by at least one other later in the year.

Advisory Council's Annual Report

The Advisory Council, a standing committee which advises the Lord President of the Council, has published its annual report. In this it discusses financing research in British Universities and concludes that the present system of multi-sources of finance is desirable and that any gaps in the country's research efforts which might tend to arise as a result can be eliminated by proper co-ordination between fund-providing bodies. The Council considers that the research councils should be enabled to provide grants to finance the purchase of expensive equipment. Total number of scientists and engineers qualified in 1957 is estimated at 13,000, compared with 11,000 in 1955. By 1970 the number is expected to rise to 22,500. The greatest problem in increasing output of qualified people is regarded as the provision of an adequate number of science and mathematics teachers in the schools.

Calder Hall Complete

No. 4 reactor at Calder Hall diverged on Dec. 8; the reactor will be run up to full power over the next two or three months. The first two reactors, comprising Calder Hall A, have been feeding electricity to the National Grid since Feb., 1957. No. 1 of Calder B, work on which was started in the summer of 1955, went critical in March, 1958, but power generation was delayed by an accident to a turbo-generator; repairs are practically complete. The station will have a capacity of 184 MW and supply 140 MW to the grid.

Uranium for Japan—Tenders Invited

Ten countries have been invited to submit tenders for 3 tons of natural uranium in ingot or billet form, density greater than 18.8 g/cc and with grain size not more than 200 μ. Japan's request should enable I.A.E.A. to work out machinery for handling fuel inquiries and may lead to the establishment of world prices. The present arrangement is somewhat cumbersome, but does eliminate the necessity for individual bilateral agreements. The manner in which this purchase is handled could materially affect status of I.A.E.A.

A.E.C. Narrows Field for Reactor Schemes

The third invitation under the A.E.C.'s power demonstration reactor programme has been modified to provide that the Commission, prior to entering into any new agreements, will make public announcements inviting proposals for reactor projects it considers technically desirable. Such invitations will give consideration to recommendations made by industry. Proposals not related to an A.E.C. defined project will not be considered. Final date for completion is now established at June 30, 1964, corresponding to final date for Commission approval of June 30, 1959.

A.E.C. Widens Licence Range

Bearing in mind the increasing demand for fissile material for uses other than those originally envisaged, such as plutonium-beryllium sources for oil well logging, the A.E.C. has amended its special nuclear material regulations to allow such applications to be accommodated. Those licensees already authorized to possess more than 500 g contained U^{235} or 300 g plutonium and U^{233} will now be required to institute full criticality prevention procedures and to ensure that employees are trained in emergency drill.

Reactor Status Reports Required by A.E.C.

Notice is given by the A.E.C. that it proposes to demand the submission of quarterly status reports by reactor owners during the period of construction of licensed reactors. Data received will become part of a readily available centralized source of information on the status of projects in the U.S. The result of this would be to minimize advantages on know-how accruing to companies undertaking reactor development financed by the A.E.C. The A.E.C. is also to make a charge for access permits, and is proposing to make public correspondence relating to licensing actions and reports of radiation accidents, in addition to special reports relating to safety.

Standardization of Fuel Elements

Sylvania-Corning in the U.S. announced at the recent meeting of the American Nuclear Society that standard fuel elements for nuclear reactors would be produced for off-the-shelf sale. Standard types, applicable to low power research reactors are based on types currently in use across the U.S. Standardization and semi-mass production should do much to progressively bring down the cost of fuel element fabrication.

Pressure Vessel Design Changes?

The paper delivered to the Institution of Mechanical Engineers on Dec. 5 describes experimental work conducted at John Thompson's on the stress distribution in a band-reinforced pressure vessel. Presentation of this paper and its reception indicates a growing acceptance of the idea of reinforced vessels which, in turn, could materially affect the design of compact high-temperature high-pressure reactor systems. The British Standards Institution has recently published a revision of BS 1500 but notes that further modifications to design stresses imposed by this standard should be possible when adequate data have been accumulated. A further subject requiring consideration is acceptance procedure for pressure-vessel plate, particularly as regards lamination testing.

G.E.'s All-out Bid for Massive BWR Development

General Electric has put forward two-pronged proposals to industry and the A.E.C. for a large-scale development programme on the BWR. Under Operation Sunrise, a comprehensive series of experimental reactors is envisaged and under Operation Know-how utility companies are encouraged to buy mass-produced 5 MW(E) plants to gain experience in operating nuclear powerplant (see P.37). The reception given these proposals has, however, been cautious. Utility companies seem suspicious of what could develop into a monopoly approach and are not yet convinced that the BWR is the ultimate type best suited to their purposes. Nevertheless, reaction has not been completely cold and, should it once get started, Operation Know-how could very well snowball to success. Operation Sunrise must be very largely dependent on the willingness of the A.E.C. to back one reactor type so heavily and to align itself with one particular company, although it is not proposed that G.E. should build all the Sunrise reactors.

PRESSURE-TUBE FUEL ELEMENTS

Manufacturing Methods and Problems

By E. BODMER, P. de HALLER and P. SULZER
(*Sulzer Bros.*)

Pressurized-tube fuel elements can often offer technical and economic advantages over a pressure vessel in reactor design. A number of problems investigated by the Sulzer nuclear research laboratories are discussed, with particular reference to the manufacture of the internally cooled pressurized-tube elements proposed by the company by a zone melting process.

THE chief advantage offered by the use of pressurized-tube fuel elements in heavy-water moderated reactors using natural uranium as fuel is that the expensive pressure vessel can be dispensed with.

Reactor projects embodying this principle have been reported in which the fuel element consists of a pressurized tube of relatively large dimensions with a group of canned rods of metallic uranium or uranium oxide inside it. A fuel element of this type is not very suitable, however, for operation with natural uranium, especially at high pressures, owing to the considerable wall thickness of the outer (pressurized) tube and the high neutron absorption which this entails.

A substantial saving in absorbent constructional materials is achieved, and with it a better neutron balance, if nests of uranium-jacketed pressurized tubes with internal canning are provided as fuel elements.

In the design developed by Sulzer Brothers*, heat transport is effected from the inside by means of water under pressure; the wall thicknesses of the relatively small-calibre zirconium tubes (12-18 mm) which are embedded in the metallic uranium do not exceed 1.5 mm even for pressures of over 100 atmospheres. With this arrangement the individual tube does not require any outer canning; the whole tube nest is surrounded by a thin-walled aluminium or zirconium shell to prevent the escape of fission products. Elements of the same design may also be used for other coolants or for boiling-water systems.

Metallurgical and design considerations point to Zircaloy-2 as a suitable material for the manufacture of pressurized-tube elements.

There are fundamentally two methods of fabricating the pressurized-tube elements envisaged in the Sulzer reactor project:

(1) by shaping the metals in the solid state (co-extrusion).
(2) by shaping the uranium in the molten state (continuous casting, zone melting).

Co-extrusion

The possibilities of manufacturing widely differing types of fuel elements by the co-extrusion process were reviewed in detail by A. R. Kaufmann at the Fuel Elements Conference in Paris on November 18-23, 1957. The process involves shaping the fissile material with its canning into an accurately dimensioned fuel element by a single operation in an extrusion press. As this must be done at high temperature, measures must be taken to prevent the deleterious absorption of gas. The tube is sheathed for this purpose in a copper shell and the space between shell and tube is evacuated. Extruding on a mandrel through the die leads to the desired pressured welding of fissile material and canning. The copper shell is then removed in an acid bath, and heat treatment gets rid of the compression texture of the fissile material, which is unfavourable for reactor operation.

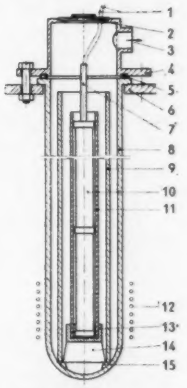


Fig. 1.—Diagram of zone melting apparatus for pressurized-tube fuel elements with internal canning.
(1) Thermo-couples, (2) Sight glass, (3) Connection to vacuum pump, (4) Stainless steel head, (5) Packing ring, (6) Supporting plate, (7) Zircaloy-2 tube, (8) Quartz vacuum vessel, (9) Quartz reflector, (10) Graphite mould, (11) Mould holder, (12) Induction coil, (13) Base plate, (14) Support, (15) Quartz block.

A report† by the above author sets forth clearly the possibilities, problems and limitations of fuel-element fabrication by the co-extrusion process.

Melting Processes

The manufacture of pressurized-tube elements by a continuous casting process is complicated and does not appear to have been developed to the industrial stage as yet.

On the other hand, manufacture of the elements by the zone melting process developed by Sulzer Brothers does not present any unusual equipment problems, and this method of fabrication may, therefore, be considered in more detail.

The basic principle of the process is that Zircaloy-2, which has a high melting point and is still of adequate strength at the melting point of uranium, makes a very good metallic bond with uranium temporarily brought to the molten state. Pre-cast uranium cylinders are pushed over a tube of Zircaloy-2. A suitable permanent mould is then made around this assembly, and a zone melting process, carried out in a vacuum from bottom to top, produces a bond between the fissile and canning materials while at the same time shaping the uranium jacket to the form of the mould.

Fig. 1 is a diagram of a set-up for producing zone melted elements. A quartz tube (8) serves as a vacuum vessel and

* A. F. Fritzsche and P. de Haller, "Sulzer Project for a Prototype Heavy Water Power Reactor for Location in an Underground Cavern," 2nd. Int. Conf. on Peaceful Uses of At. En., P/246.

† A. R. Kaufmann *et al.*, "Zirconium Cladding of Uranium and Uranium Alloys by Co-Extrusion," NMI-TJ-8, 4th October, 1957.

is protected from excessive heating by a reflector (9). Inside this reflector is a ceramic skeleton mould holder (11), the purpose of which is to keep the multisectional permanent mould (10) within the permissible geometrical tolerances. A stainless steel head (4) is flanged to the top of the vacuum vessel and is provided with all necessary passages (e.g., for thermo-couples) and other fittings (e.g., sight glass, connection to vacuum pump, etc.). Outside the vessel is a high frequency induction coil (12), which can be moved up and down.

The permanent mould is accurately machined from graphite, and it has been found that the most practical procedure was to design it in separate sections capable of being taken apart axially and radially. This enables the element to be assembled, step by step, before the zone-melting process, and afterwards to be removed without difficulty. The modular assembly principle gives the mould unit a long service life, since individual sections which become defective can be replaced by new ones. Fig. 2 shows the top and bottom end sections of a graphite mould, and the method of joining by means of graphite clamping sleeves, which is the same for all intermediate sections. Fig. 3 shows a schematic drawing of a mould in section, with the fuel element in position ready for the zone melting process.

The melting process is carried out from the bottom upwards with as small a melting zone as possible, thus bringing about a metallic bond between the Zircaloy-2 and the fissile material in a very short time with clean filling of the mould. The temperature of the melt and the duration of the molten phase at a given point are purely empirical values.

The intermediate graphite rings (3 in Fig. 3), though not absolutely essential for the zone melting process, have the advantage—particularly with alloyed uranium—of counteracting any segregation during the zone melting process, and later, in reactor service, of taking up the swelling of the fissile material. The intermediate rings must be drilled as shown in Fig. 3, so that molten uranium may flow downwards to give clean mould filling. They serve the additional purpose of centring the Zircaloy-2 tube.

Fig. 4 shows a specimen of the zone-melted element as removed from the graphite mould and without any further treatment. The intermediate rings (4) can be seen clearly, likewise at the top a baggy skin of uranium oxide (2) from which the molten uranium required for filling the mould has flowed downwards.

The zone melting process brings about a tough and flawless metallic bond. The mutual interpenetration of uranium and Zircaloy-2 produces an almost continuous transition from the region of high Zircaloy-2 concentration to the region of high uranium concentration. Marked discontinuities, such as are usually found in bonds between metallic uranium and other metals as a result of the formation of very brittle intermetallic layers, do not occur in the zone melting process when it is carried out correctly.

Fig. 5 shows the bonding of uranium and Zircaloy-2 in an unalloyed uranium element after the zone melting process.

A metallic bond of this quality, however, can only be achieved with the zone melting process if the initial carbon content of the uranium is very low and does not undergo any substantial increase during melting inside the graphite mould. It is well known that the carbon present in the uranium in the form of carbide reacts with the zirconium, producing the thermo-dynamically stabler zirconium carbide (ZrC). This forms an extremely brittle intermediate layer (Fig. 6) between the uranium and zirconium, thus

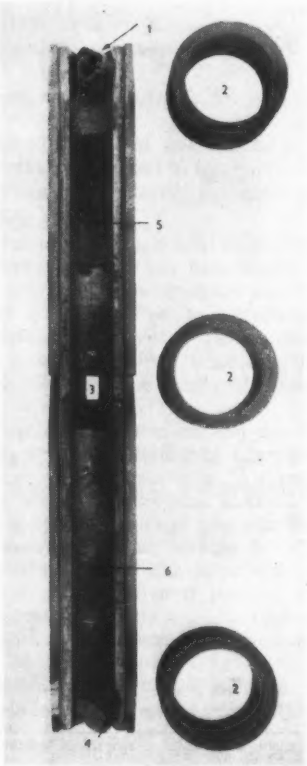
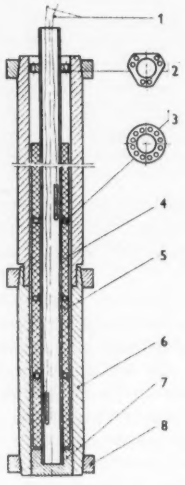


Fig. 2.—The graphite mould.

(1) Centring ring, (2) Clamping sleeves, (3) Coupling junction, (4) Sealing plug, (5) Top and piece, (6) Bottom and piece.

Fig. 3.—(Below) Section through the graphite mould containing the fuel element.

(1) Thermo-couples, (2) Graphite centring ring, (3) Drilled intermediate graphite rings, (4) Zircaloy-2 tube, (5) Uranium cylinder, (6) Mould, (7) Sealing plug, (8) Clamping sleeve.



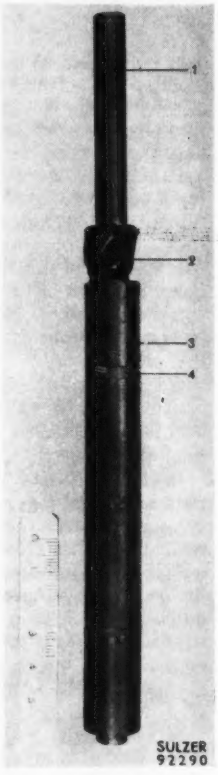


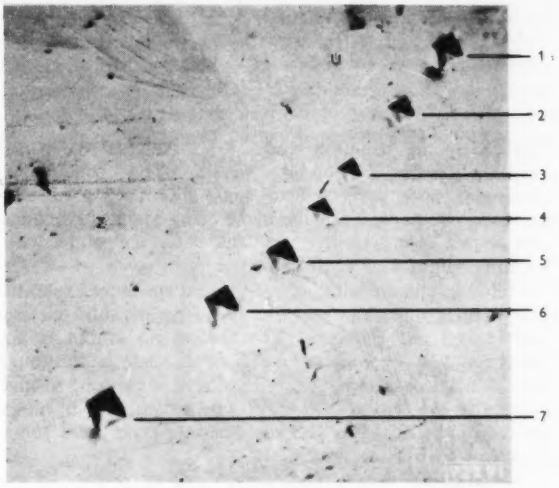
Fig. 4.—(Right) Zone-melted test element.

(1) Zircaloy-2 tube, (2) Uranium oxide skin, (3) Uranium jacket, (4) Intermediate ring.

rendering a ductile metallic bond impossible. Heat transfer and adhesion strength are not substantially affected by the carbide layer, but the extreme brittleness of zirconium carbide results in high susceptibility to cracks in this layer. The swelling of the uranium in reactor operation therefore quickly leads to the destruction of the zirconium carbide layer and to the undesirable local accumulation of heat.

Fig. 6.—(Right) Micro-section (×240) of a uranium-Zircaloy-2 bond with an intermediate layer of zirconium carbide. (U Uranium; ZrC Zirconium carbide; Z Zircaloy-2.)
Vickers hardness, 25 gr.: (1) 340, (2) 340, (3) 320, (4) 315, (5) approx. 1,800, (6) 290, (7) 285, (8) 270, (9) 200.

Fig. 5.—(Below) Micro-section (×240) of the uranium-Zircaloy-2 bond. (U Uranium; Z Zircaloy-2.)
Vickers hardness, 25 gr.: (1) 345, (2) 430, (3) 460, (4) 430, (5) 295, (6) 270, (7) 190.



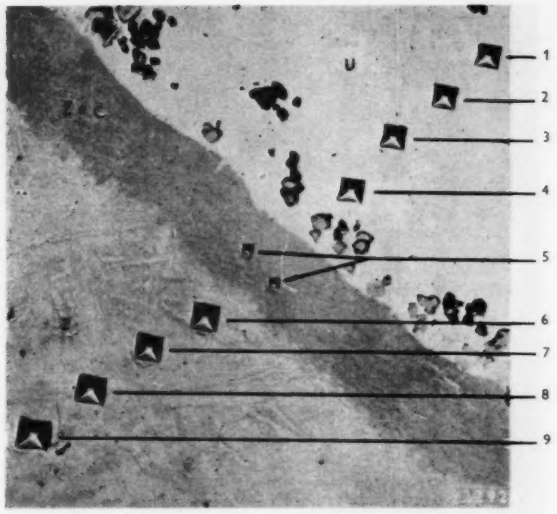
In the zone melting process the pick-up of carbon by the uranium, and thus the formation of a zirconium carbide layer, can be suppressed by applying a suitable wash to the graphite mould and intermediate rings. Complete protection against carburization can of course also be obtained by means of external canning with zirconium or zirconium alloy in the form of a thin-walled tube between the uranium and the mould. This outer canning is also bonded to the uranium in the melting process. Finally, recourse might be had to ceramic moulds as a means of preventing carburization. This alternative, however, offers little interest on account of the short life, insufficient dimensional accuracy and high price of the ceramic mould sections.

Appropriate heat treatment removes the casting stresses present after the zone melting process, as exemplified by the relatively high uranium hardness in Fig. 5, and also brings about a welcome grain refinement.

Corrosion Tests

The evaluation of static corrosion tests with hot water on zone-melted test elements of unalloyed uranium gave the results shown in Fig. 7. The test conditions were as follows:

After the zone melting process a leak of approx. 3 mm² was made in the inside canning, and the bottom end of the Zircaloy-2 tube was soldered up. The test element was filled with pure water through the other end, and placed under an inert-gas pressure of 100 atmospheres. It was then brought up to the desired temperature in a furnace



within a period of 25 minutes. From the moment when the test temperature was reached, the time during which the test element resisted the corrosive effect of the hot water was measured. The critical time between the attainment of the test temperature and the bursting of the uranium jacket is shown in Fig. 7 as a function of the test temperature. The critical times at 200°C, 250°C and 300°C are mean values obtained from at least six tests.

The damage to the element revealed at the end of a corrosion test was always of a similar nature: the uranium jacket burst spontaneously, and the water evaporated into the inert atmosphere of the furnace through the resultant crack. No intensive burning caused by the escape of steam was observed on the uranium jacket. Pronounced cracking of the canning material round the leak, or even bulging and bursting at points far removed from the leak, such as are typical of rod elements, were never observed.

Fig. 7.—Evaluation of static corrosion tests with hot water on zone-melted test elements. Abscissa: Test temperature. Ordinate: Critical time from attainment of test temperature to bursting of uranium jacket (in hours).

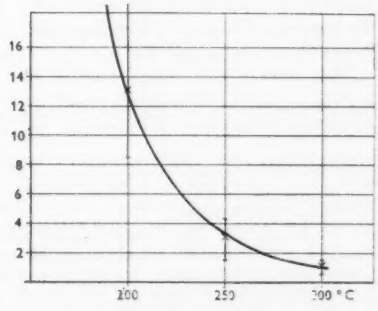


Fig. 8 shows a typical section through a corroded element at the level of the leak. It will be seen that the corrosion front has spread around the Zircaloy-2 leak. The Zircaloy-2 tube has been dented inwards by the uranium oxide, which occupies a greater volume than the metallic uranium from which it has originated. The metallic bond between the uranium and Zircaloy-2 does not appear to be more susceptible to corrosion than the fissile material itself.

Similar tests with a U-2 w/o Zr alloy are now in progress, and the first results indicate that the critical times are somewhat longer. It is proposed to carry out analogous corrosion tests on co-extruded elements.

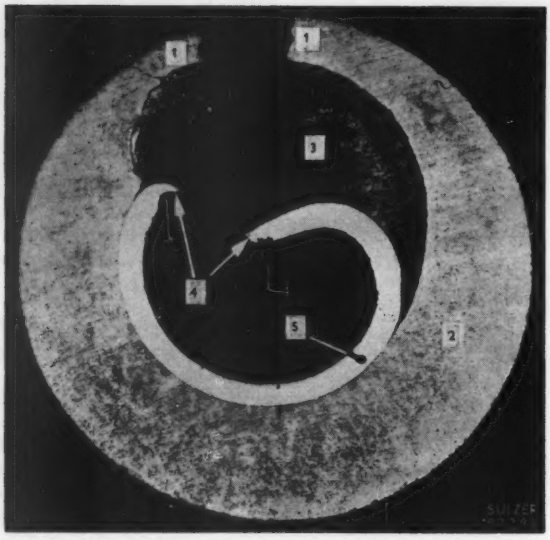


Fig. 8. (Left)—Section through a corroded element.

(1) Crack in uranium jacket, (2) Uranium, (3) Uranium oxide, (4) Leak in Zircaloy-2 tube, (5) Zircaloy-2 tube.

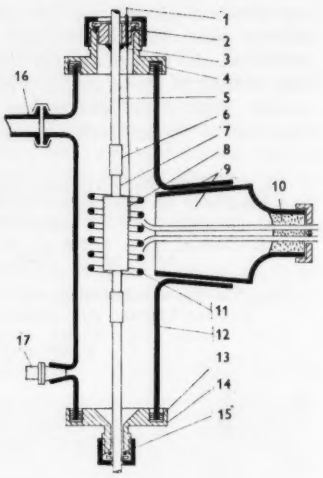


Fig. 9. (Right)—Equipment for alternating temperature tests on watercooled pressurized-tube elements.

(1) Thermocouple, (2) Rubber packing, (3) Hard solder, (4) Top closure, (5) Brass tube, (6) Steel connecting piece, (7) Zircaloy-2 tube, (8) Uranium jacket, (9) Glass taper piece, (10) Araldite joint, (11) Induction coil, (12) Glass vacuum vessel, (13) Araldite joint, (14) Bottom closure, (15) Rubber packing, (16) Vacuum connection, (17) Vacuum measuring point.

Alternating Temperature Tests

Zone-melted test elements were subjected to alternating temperatures in a vacuum. Fig. 9 is a diagram of the test rig. The specimens were of the following dimensions:

Zircaloy-2 tube:	Inside diameter	8 mm
	Outside diameter	10 mm
	Wall thickness	1 mm
Uranium jacket:	Wall thickness	3.2 mm
	Length	50 mm

The tests were intended to elucidate the following points:

(1) Behaviour of the metal bonding layer between uranium and Zircaloy-2 when subjected to static and cyclic temperature tests under conditions similar to those obtaining in the reactor.

(2) Behaviour of the internally cooled uranium jacket during the temperature tests.

Temperatures of 550°C at the surface of the uranium were measured in the static tests at a maximum current input to the water of 400 watts/cm². The temperature in the uranium-Zircaloy-2 bonding layer was found by calculation to be about 350°C.

The cyclic tests were carried out at inputs of 300 watts/cm² (at the Zircaloy-2-water transition). The corresponding temperatures were about 420°C (measured) at the surface of the uranium and 270°C (calculated) in the uranium-Zircaloy-2 bonding layer. The zone-melted specimens were subjected to 1,000 alternations of temperature, the duration of the cycle being about 30 seconds. The water inlet temperature was 9°C, the outlet temperature about 12.5°C at full load.

Metallographic evaluation of the test specimens revealed that neither the static nor the cyclic temperature stresses had caused any damage. There were no cracks in the metal bond between canning and fissile material, although the diffusion zone is relatively hard and is exposed to high stresses in the temperature field. In general, the hardness figures of the uranium and the bonding layer were somewhat lower after the tests.

No negative observations were made in respect of the stability of the shape of the uranium subjected to the alternating temperature tests, and it is possible that the uranium temperature differences were too small to produce the well-known deformation phenomena. The geometric dimensions of the uranium jacket were unchanged after the tests.

It would seem then that this method of manufacture is satisfactory as regards bonding, mechanical strength and corrosion resistance. Carburization, causing a brittle layer of zirconium carbide between the uranium and the Zircaloy is a problem requiring attention: work is proceeding on this.

Tubes Sous Pression

L'emploi de tubes sous pression dans la construction des réacteurs a souvent été considéré comme une alternative d'un récipient sous pression. On fait remarquer, toutefois, que lorsque le combustible est placé à l'intérieur du tube sous pression, par suite du diamètre, relativement grand une épaisseur de paroi de tube considérable est nécessaire. On suggère, en conséquence, qu'une alternative préférable serait représentée par l'emploi de tubes sous pression de petit diamètre à l'intérieur du combustible.

Le présent article décrit une méthode de fabrication de tels éléments par un procédé de fusion de zone que l'on dit donner une très bonne liaison entre un tube à l'alliage " Zircaloy-2 " et de l'uranium métallique.

Hochdruck-Rohre

Die Verwendung von Hochdruck-Rohren bei der Konstruktion von Reaktoren als Alternative zum Hochdruck-Behälter ist bereits häufig in Betracht gezogen worden. Es wird indessen darauf hingewiesen, dass, wenn der Brennstoff im Inneren des Hochdruck-Rohres untergebracht wird, dann wegen des verhältnismässig grossen Durchmessers eine beträchtliche Rohr-Wandstärke erforderlich wird. Es wird deswegen als vorzuziehende Alternative vorgeschlagen Hochdruck-Rohre von kleinem Durchmesser zu verwenden, mit dem Brennstoff ausserhalb der Rohre.

Der Aufsatz beschreibt ein Verfahren solche Elemente unter Verwendung eines Zonen-Schmelzverfahrens zu fabrizieren, und es wird berichtet, dass dies eine sehr gute Bindung ergeben hat zwischen einem Rohr aus Zircaloy-2 und Uran-Metall.

Tubos de Presion

El uso de tubos de presión en la construcción de reactores ha sido frecuentemente considerado como una alternativa a un recipiente de presión. Sin embargo, se hace ver que cuando el combustible se coloca dentro del tubo de presión, debido a su diámetro comparativamente grande, es necesario que haya un considerable espesor de pared de tubo. Por lo tanto, se sugiere que una alternativa preferible seria el uso de tubos de presión de un diámetro pequeño dentro del combustible.

Este artículo describe un método de fabricar tales elementos por un procedimiento de derretimiento de zona que se dice ofrece una ligazón muy buena entre un tubo de aleación " Zircaloy-2 " y uranio metálico.

The Vickers Linear Accelerator

Multi-BeV Unit More Than 2 Miles Long Envisaged

Particulars are given of a linear accelerator design suitable for energies in the range 5-30 BeV. The 20 BeV unit would be some 3,700 metres long.

THE growing interest of industry in the techniques associated with high energy machines is illustrated by the decision of Vickers Research, Ltd., to develop from within its own resources a design for Multi-BeV linear accelerators. The organizational and operational obstacles inherent in the great physical size, quite apart from the cost, of such machines have been surmounted by breaking down the design into separate sub-accelerator modules of approximately 100 MeV each. The design developed is suitable for energies of 5 to 30 BeV although 20 BeV has been chosen as the target level in the first instance. The modular technique is based on the development of a 20 MW klystron amplifier which operates at approximately 3,000 Mc/s.

Envisaged, then, is an electron accelerator of 20 BeV capacity, with an 18 mA pulse, and capable of 70 kW, comprising 180 klystron units each producing 20-MW, 5 μ sec pulses at a repetition rate of 50/sec. Each sub-accelerator unit is 20 m in length, making a total length for the 20 BeV machine (and including the junctions between each sub-unit) of 3,700 m. The energy gradient of something less than 6 MeV/m, whilst on the surface somewhat low for a high energy design, has been optimized taking into consideration the cost of the klystron and moderator units and that of the sub-accelerators and other items whose cost is proportional to length. For complete accelerators outside the range 5-30 BeV, some reconsideration of this energy gradient would be required.

Construction

The construction of an accelerator over two miles long involves many interesting engineering problems; not least of these is the civil engineering associated with the preparation of a straight run of this length. If it is possible to site the machine in open and reasonably flat country, installation above ground with light weather protection is likely to provide the most easily maintained and cheapest machine, particularly if radiation screening on the sides is not required. If, on the other hand, the accelerator is built in populated areas, tunnelling some 40 or 50 ft below ground would be indicated and, if the cost could be justified, a double tunnel, the second tunnel containing the modulator units and auxiliaries, with on-site servicing during operation would provide the most elegant solution.

If above ground, five 4-m sections of wave guide and four 10-cm pumping sections are assembled and aligned on the supporting framework and located axially at one end only of the framework to allow for differential expansion (Fig. 1). The assembly is such as to locate the guide

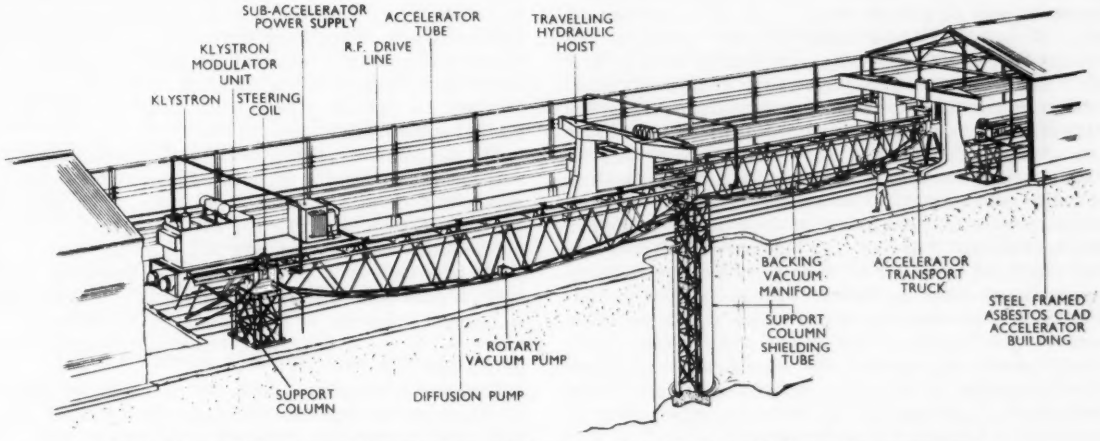


Fig. 1.—General above-ground arrangement, showing one sub-accelerator withdrawn for maintenance.

in a standard position with respect to the support points of the framework. In this way it is possible to replace a faulty sub-accelerator with a spare and yet maintain the alignment of the composite accelerator. The sub-accelerator framework also supports the vacuum pumping gear and other incidental equipment, including the steering coils at the sub-accelerator junction. Double isolation valves are provided, which allow the removal of the sub-accelerator whilst still retaining high vacuum conditions in this, and remaining, sub-accelerators. The two spherical fittings at each end of the supporting framework transmit the load of the sub-accelerators to the jacking system.

For an underground installation, the tunnel itself would act as the stiff beam necessary for the support of the sub-unit. The single tunnel is considerably less expensive than the double tunnel and permits the installation and alignment of a complete sub-accelerator should a major fault develop.

Steering systems are provided between each sub-accelerator unit but, none the less, only limited correction is possible and the design tolerance is ± 0.5 cm in the 20-m length. Overall, the end of the accelerator must be

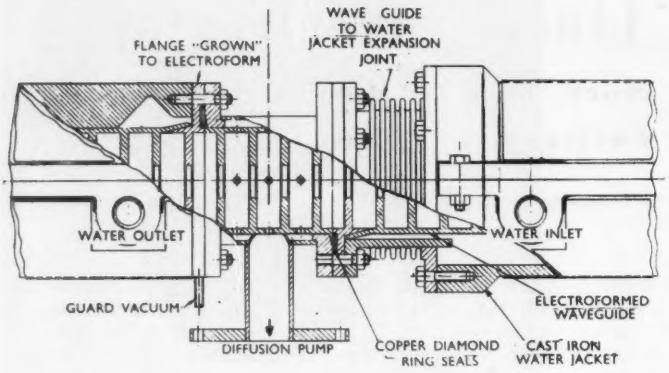


Fig. 2.—(Left) Method of waveguide construction.

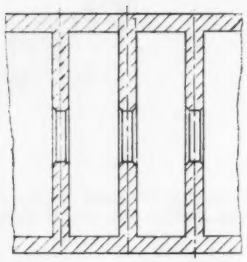


Fig. 3.—(Right) Enlarged view of iris unit.

within 10 cm of the line projected from the axis of the injector, in order to limit beam spread at the target to 0.5 cm.

Unit Construction

Ease and speed of maintenance is a major design criterion, the average failure rate of the 180 klystrons (taking an individual life of 2,000 h) being 11 per 120 hours operating period. To facilitate replacement, the modulator-klystron is built as a single unit, housed in a common oil tank. It can be works-assembled and tuned in the servicing bay; overall dimensions are 4 ft by 12 ft by 6 ft high. The tank contains a three-phase stepless regulator, transformer and full wave metal rectifier power unit, which is supplied by a 415-V, three-phase, 50-c/s line and produces a d.c. output of 20 kW at 35 kV. This output is supplied to the charging choke, ten section pulse-forming network and pulse transformer. The klystron itself is mounted through a hole in the modulator tank near the output pulse transformer, and the high voltage connections are made under oil by means of a plug on the gun bushing. Some essential items are located outside the tank, as for instance the pressurized spark-gap switch and trigger electronics, which are housed in a cubicle at the end.

Total power requirements for the 20-BeV accelerator are estimated to be 10 MVA for full operation. This includes services, cranes, etc.; the 180 sub-accelerators draw some 8 MVA from an 11-kV ring main.

It is suggested that remotely switched duplicates are provided for all electrical items on the accelerator which are at all likely to fail, and which place more than, say, 10% of the accelerator out of action. An operational cycle of five days on, two days maintenance is envisaged.

Accelerator Tube

The design of the wave guide is based on the constant field principle as against the constant impedance system and strictly this should involve the tapering of the dimensions of both the iris and the cell diameter along the 20-m length. To avoid this, it is proposed that the sub-accelerator should consist of five constant impedance sections of equal length suitably chosen to approximate in step fashion to the constant field. The wave guide is built by electro-forming, considerable development having gone into the production of non-porous, oxygen-free high purity copper shapes to accurate dimensions. The method developed is both inexpensive and reliable and is readily suited to the mass production necessary when a 20-BeV machine is being built. Permissible tolerances on the wave guide section vary between 0.0003 in. and 0.001 in.

Such stringency points to the importance of strict temperature control; 1°C temperature change leads to an energy loss of approximately 1%. This may be corrected by a corresponding frequency change, provided the change is uniform and is the same for all sub-accelerators. A random variation cannot be corrected in this way. As a result it has been considered desirable to enclose the wave guide in a water jacket rather than surround it by cooling pipes.

Considering next the temperature difference across the ends of the complete accelerator, if the frequency is correct for the centre of the accelerator, then an energy loss of 1% results from a temperature difference of 4°C (across the whole accelerator). Thermal insulation is necessary for the water feed main to achieve this tolerance and possibly to include thermostats and heaters in the sub-accelerator feeds.

The electron source is a 50-kV hot-cathode temperature limited electron gun. A spare cathode assembly is mounted within the vacuum envelope and may be brought into service by remote control. The electron beam is condensed magnetically and injected into a 2-3 m corrugated wave guide buncher. In this region a radial constraint on the beam is provided by a uni-directional axial magnetic field. A Pegasus computer is being used in the design of this buncher. The output bunch occupies a phase-angle spread of less than 10°.

The earth's magnetic field is also a complicating factor, in that without magnetic shielding, the deflection of the beam over its two-mile track would amount to some 64 m and, even if the tube were bent to follow this path, the spread of the beam would be some 320 cm; furthermore the random variation of the earth's field is of the order of 0.2% in a day. A reduction in intensity of over 100 is provided by the cast-iron water jacket and mu-metal screen and the steering fields provide the additional re-alignment.

The accelerator tube is run at a pressure of around 10^{-5} mm Hg at the worst point which is mid-way between two pumps. Each sub-accelerator unit system is self-contained and comprises an Edwards 1 SC.150 gas ballast rotary pump backing (in the above-ground design) six 2-in. fractionating diffusion pumps fitted with integral baffles which reduce the individual pumping speed to 30l/sec.

At present a modulator-klystron unit has been built and the modulator section is undergoing a series of exhaustive high-power tests. The electro-forming technique has been fully developed and engineering designs are complete as far as is possible without reference to a specific site. It is expected that construction of a complete 20 m sub-accelerator unit will begin early in the New Year.

In addition to this major work on the 20-BeV design a smaller irradiation linear accelerator has been designed with an output of 4 kW at 10 MeV.

BORON—

and Boron-containing Materials

By H. C. COWEN, M.Sc., Ph.D.
(*Culcheth Laboratories, U.K.A.E.A., I.G.*

Availability, absence of penetrating capture γ-radiation and effectiveness over a range of neutron energies make boron one of the most attractive of the high cross-section elements which can be used for control and shielding purposes. These favourable properties have been exploited in a wide range of boron-containing materials, the efficiency of which can be enhanced by enrichment of the B-10 content of the element.

CONSIDERING the natural elements, boron stands sixth in order of thermal neutron capture cross-section (Table 1). With the exception of cadmium, however, no element of higher cross-section is as readily available, and the cross-section of cadmium falls very sharply after exhibiting a resonance peak at 0.18 eV. Furthermore, most except boron emit penetrating capture γ-radiation. It is for these reasons that boron has achieved an importance in the field of absorber materials not as yet shared by other elements.

Boron does, however, have an important disadvantage. Its neutron absorbing properties are due to the (n, α) reaction undergone by the isotope of mass 10, and this reaction can give rise to radiation damage, which is likely to be serious where high burn-up is envisaged. This aspect of the use of boron in reactor technology is considered in a subsequent section.

Boron has also an important rôle to play in the field of neutron physics, since the emission of the α-particle which occurs on neutron absorption is readily recorded, and leads to the widespread use of boron in neutron detectors and counters. It is also extensively used as a standard against which the cross-section of other elements is measured, its superiority in this connection being associated with the absence of resonance peaks of the type exhibited, for example, by cadmium.

OCCURRENCE AND EXTRACTION

Boron is present in the earth's crust to an estimated 3 ppm and is thus a relatively rare element. It occurs in fairly concentrated form, however, the deposits generally consisting of borates or borosilicates. Some of the most important workable deposits are in California where large quantities of kernite ($Na_2B_4O_7.4H_2O$), colemanite ($Ca_2B_6O_{11}.5H_2O$) and ulexite ($NaBO_2.CaB_4O_7.8H_2O$) are found, and volcanic regions in Italy and elsewhere also yield significant quantities in the form of boric acid.

For various reasons it is not easy to prepare elementary boron in a pure form by the common extraction methods (although it is important to note that analytical data expressed as wt.% can be misleading in view of the low atomic weight of the element). Thus, reductions may result in the formation of finely divided boron highly dispersed in an oxide or halide matrix, and the generally reactive nature of the element in such a form—especially its affinity of oxygen—makes the processing of such reaction products difficult. Furthermore, many of the common reducing agents tend to form borides, and indeed these were mistaken for the elementary material in some of the early attempts to isolate boron. Such difficulties are aggravated by analytical problems, and it is therefore not surprising that some of the available grades of boron are of low or uncertain purity.

TABLE 1
Natural elements arranged in order of capture cross-section for thermal neutrons (0.025 eV)

Element	Thermal neutron capture cross-section (barns/atom)
Gadolinium	46,000
Samarium	5,500
Europium	4,600
Cadmium	2,550
Dysprosium	1,100
Boron	755

These remarks apply particularly to thermochemically produced material. Although boron can be prepared by this method, using a variety of reducing agents, including aluminium, calcium, magnesium, sodium and potassium (the starting material usually being B_2O_3 or KBF_4), the product is usually heavily contaminated with oxygen and the reducing metal, the latter being present as the boride in many cases. The possibility of a vapour phase reduction of BF_3 gas has also been demonstrated[1], but the purity obtainable by this method is little better.

Electrolytic processes have, in some instances, proved more successful. This can be attributed to the collection of the boron by the cathode and also to the coarser form in which it can be deposited, both factors simplifying the subsequent processing. In particular, high purity has been claimed for a process patented by Cooper[2] involving electrolysis of a KCl/KBF_4 melt contained in a graphite crucible which acts as the anode, the cathode being of copper or iron. The process is in part thermochemical in nature, the primary effect of the current being to liberate potassium which, in turn, reduces the boron. It has been used in the U.S. in connection with work on the isotope separation, where it yields material[3] not less than 94% pure.

The isotope project also stimulated intensive study of the production of boron by deposition on a hot wire from volatile compounds[4]. This technique using hydrogen and BCl_3 and depositing on graphite rods has now been patented by Fetterley[5] and is used in the U.S. as a commercial process by the Norton Company[6] who achieve purities above 98%. Feed materials other than BCl_3 can be used. In reviewing the technique, Powell[7] *et al.* list the following possibilities:—

(i) Hydrogen reduction of a boron halide (not however, BF_3).

(ii) Thermal decomposition of a boron halide (again excluding BF_3).

(iii) Thermal decomposition of a boron hydride (e.g., diborane).

(iv) Thermal decomposition of organo-boron compounds.

Undoubtedly the purest forms of boron have been produced by such techniques. The main impurity in the Norton product is carbon picked up from the graphite rods, and work described by Powell using hydrogen and

BBr_3 in conjunction with tantalum filaments indicates the possibility of achieving an estimated purity of 99.9%.

Most of the available grades of boron are classified as amorphous or crystalline, but since X-ray diffraction patterns of the element are inevitably difficult to obtain as a result of its low scattering power, the crystallographic significance of such labels is uncertain. Tables A2 and A3 show the analysis of some of the grades of boron available from two sources. For quantities of the order of several pounds, prices vary from £8/lb for the low grades to about £28/lb for the highest purity material; larger quantities are relatively cheaper.

ISOTOPE SEPARATION

Natural boron consists of about 18.8% of the strongly absorbing isotope of mass 10, the remainder consisting of the 11-isotope of relatively low cross-section. It follows that the value of boron as a neutron absorber can be considerably enhanced by removal of the latter. Isotope separation can, in fact, raise the position of boron from sixth to fourth in Table 1. Conversely, any potential application of boron within the fission zone of a reactor other than for control purposes and which would be precluded by cross-section considerations may become feasible by the use of substantially pure 11-isotope. At the present time however, work on the isotope separation has been aimed mainly at the production of the 10-isotope with a view to increasing the effectiveness of boron as an absorber.

Two methods have been used for the isotope separation. The first consists of the fractional distillation of the dimethyl or diethyl ether complex of BF_3. (More recent work[11, 12] has been aimed at investigating the potentialities of other BF_3 complexes, in particular that formed with anisole.) This process actually operates, it is believed, by chemical exchange between the BF_3 and the complex, the latter being appreciably dissociated in the vapour phase. The second process is the low-temperature fractional distillation of BF_3 itself. In both processes the 10-isotope concentrates in the lower fractions.

Separation by means of the BF_3-ether complex has been carried out in the U.S.[3, 4, 13] and in this country[14]. The following data on the American process, which uses the dimethyl ether complex, illustrate its main characteristics. Distillation is carried out at 91°C and at an absolute pressure of 6 in. Hg. Five 20-in. diameter columns and one 6-in. diameter are connected in series to give an effective height of about 350 ft. They are of Monel construction and employ ¼ in. by ¼ in. Monel packing, the complete system providing 380 theoretical plates. Equilibrium is initially reached only after 2 to 3 months operation, but after a scheduled shut-down the steady rate is reached in about 24 hours. A reflux ratio of approximately 700 : 1 is used, and enrichment is carried out to a maximum of 95% B^{10}. The separated complex is converted either to BCl_3 which is hydrogen-reduced, or to KBF_4 from which the boron is extracted electrolytically.

Low-temperature distillation of BF_3 has been carried out in this country[15, 16] and in Russia[17]. The U.K.A.E.A. plant consists of two columns in series, each packed over a length of 57.5 ft with $\frac{1}{16}$-in. gauze Dixon rings and operated at −95°C. The pressure and vapour velocity vary throughout the plant. The first column produces material containing 50% B^{10} at the boiler. This is fed to a point near the top of the second column, which is smaller in diameter than the first, and where it is enriched to 95% B^{10} in the boiler. The equilibrium time is 23 days, and the plant can produce 26.5 kg/year.

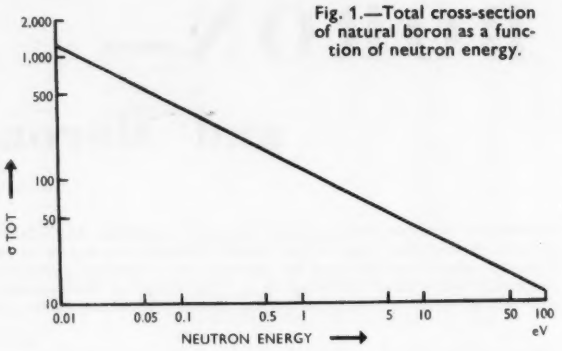


Fig. 1.—Total cross-section of natural boron as a function of neutron energy.

The main use to which boron enriched in the 10-isotope has been put is in neutron detectors and counters, and requirements have also arisen in connection with a number of reactor and nuclear physics experiments. Future applications will probably include its replacement of natural boron in control and shielding materials to reduce the necessary concentration of the element and hence simplify fabrication problems. The enriched element may also have a rôle to play in the improvement of the radiation damage properties of such materials.

PROPERTIES OF ELEMENTARY BORON

Nuclear Properties

The absorption and scattering cross-section of natural boron for thermal neutrons (0.025 eV) is shown in the Data Sheet. The overwhelming contribution to the total cross-section is due to the (n, α) reaction undergone by the approx. 18.8% of B^{10} atoms:

$$_5B^{10} + _0n^1 \rightarrow _3Li^7 + _2He^4$$

for which the isotopic cross-section for thermal neutrons is 4030± barns/atom and the "Q" value 2.791 MeV. In 94% of the neutron captures a 0.478 MeV γ-ray is emitted as a result of the decay of the excited Li^7 nucleus, and the energy imparted to the product nuclei is correspondingly reduced to 2.31 MeV. It should be noted, however, that this capture γ-radiation is soft by comparison with that emitted by most medium and heavy atoms, and as previously noted this is an important advantage which boron has over other strong neutron absorbers. Fig. 1 shows the total cross-section of natural boron as a function of neutron energy for values of the latter up to 100 eV, from which it can be seen that in this low energy region the 1/v law is accurately obeyed. For fast or fission neutrons there is much less spread in the cross-sections of the elements, and natural boron loses its superiority over a number of them. This may be seen from Fig. 2, showing macroscopic total cross-section at 8 MeV[18] as a function of atomic weight.

Both naturally occurring isotopes of boron can undergo reaction with α-particles to produce neutrons:

$$_5B^{10} + _2He^4 \rightarrow _7N^{13} + _0n^1 + 1.07 \text{ MeV}$$

$$_5B^{11} + _2He^4 \rightarrow _7N^{14} + _0n^1 + 0.15 \text{ MeV}$$

and mixtures of boron with α-emitters (e.g., radium or polonium) are used as neutron sources for calibrating laboratory equipment.

Physical Properties

The published values of many of the physical properties of elementary boron do not, unfortunately, refer to high purity material. Work by Laubengayer[19] *et al.* has led to more certain knowledge of the true values of some properties, though in other cases the position remains far

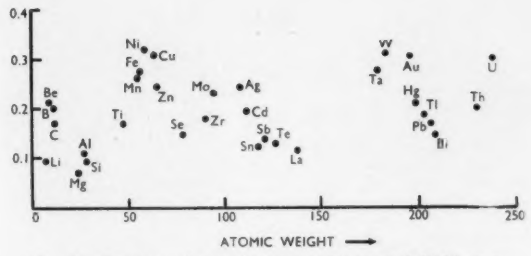


Fig. 2.—Macroscopic total cross-sections at 8 MeV as a function of atomic weight (18).

from satisfactory. There is thus no general agreement about the melting point, the literature containing values from about 2,000 to 2,500°C. Its determination is complicated by the reactivity of the material and the uncertainty of its emissivity. The value shown in the Data Sheet of 2,000 to 2,075°C is due to Cueilleron[20]; the purity of the sample is not stated but is probably high, since it was made by hydrogen reduction of BCl_3. The liquid range is fairly short, the boiling point having been estimated as 2,530°C. This is the value used by Quill[21] in deducing the vapour pressure data. The heat capacity is due to Kelley[22] and is considered accurate to ±5%. Thermal conductivity values for the dense material are not available.

Electrical conductivity values have also had to be omitted from the Data Sheet, since there is marked disagreement between published results. Thus, Weintraub[23] working with "Moissan's boron" (magnesium-reduced B_2O_3) found a value of 1.6×10^{-6} reciprocal ohms at room temperature with a million-fold increase at 600°C, but working with a single crystal of hot-wire material Laubengayer[24] *et al.* found less than a hundred-fold increase over this temperature range. Other workers[25], also using hot-wire material, have reported very large specimen-to-specimen variation.

Mechanical Properties

Pure boron in a massive high-density form is virtually unknown, except as the product of a vapour-phase deposition process. In this form it is intensely hard and brittle, and quite incapable of being worked.

Chemical Properties

The general reactivity of boron is very much dependent on its form and method of preparation. Finely divided material is of low stability, especially if the purity is only moderate or less. Thus, the 90-92A and 95-97A material indicated in Table A2 is described as being hygroscopic and oxidizing slowly on exposure to air, but not appreciably affected by boiling water, or aqueous NaOH, HCl, HF, HI, or dilute H_2SO_4. It is partly oxidized at room temperature by aqueous HNO_3, H_2O_2, $KMnO_4$ and $AgNO_3$ and is slightly attacked by hot concentrated H_2SO_4 or chromic acid in sulphuric acid. It dissolves almost completely in a boiling mixture of dilute HCl, HNO_3 and H_2SO_4, but a small amount usually remains undissolved.

Material of higher purity is not hygroscopic and is more oxidation-resistant, a 10 to 30 mesh sample of the crystalline material shown in Table A2 increasing in weight by less than 0.1% on heating for 30 minutes in air at 450°C. In the finely ground form this material reacts vigorously with concentrated HNO_3, but large particles are only slowly attacked[8]. In the massive form the oxidation-resistance of boron is further improved. Cooper[26] reports that for pressed material (composition unspecified) there is no apparent oxidation in air up to about 750°C, but that at 800°C the surface begins to show a black glaze. This coating is apparently completely protective up to about 1,000°C, but in pure oxygen at this temperature the attack is quite rapid.

The halogens react with all types of boron, the melting points of the products varying from −129°C for BF_3 to +50°C for BI_3. All but the fluoride can be hydrogen-reduced back to boron. Free energies of formation for the halides and also for the oxide are included in the Data Sheet. With a large number of metals, boron reacts to form borides; these compounds are of considerable significance from both a theoretical and technological point of view, and are discussed more fully in a subsequent section.

Crystal Structure

Elucidation of the crystal structure of boron has been hampered by the low scattering power of its atoms and a relative scarcity of specimens suitable for X-ray examination. It appears that both tetragonal and rhombohedral forms are possible, but the atomic arrangements and stabilities have yet to be clarified. Recent work is described in references[26a] and [26b], to which the reader is referred for further information.

FABRICATION

Fabrication of boron by melting and casting is virtually impossible, the main difficulty being the provision of a sufficiently inert container. Even if this problem could be satisfactorily solved, however, the indications are that the melted material would be in all respects similar to that formed by vapour phase deposition and incapable of subsequent machining. Recourse is therefore made to powder metallurgy techniques, but since boron has only poor self-bonding properties an additive is necessary. B_2O_3 is often used for this purpose. With a 2% addition it is possible to obtain boron compacts with compressive strengths of 45,000 p.s.i., and this figure can be raised to 75,000 p.s.i. with a 5% B_2O_3 addition[3]. Metal additions can also be used, or alternatively the elementary material may be replaced by a self-bonding metal boride, or by boron carbide (q.v.). The boron density of shapes fabricated by such techniques can be comparable with that of the element itself.

The following are some details of a process developed at Culcheth[27] involving the hot-pressing of boron-nickel mixtures and by means of which machinable compacts can be prepared in which the boron density is greater than 1.9 g/cm³. Boron powder of −400 mesh is mixed with 10% nickel and the mixture cold-compacted in a steel die to a maximum load of 10 ton/in.², the purpose of this being to reduce subsequent shrinkage and to avoid contamination from boron nitride used in the hot-pressing operation. After removal from the die the compact is rapidly transferred (since it tends to swell) to the hot-pressing unit, which is shown diagrammatically in Fig. 3. The die and plunger are made of graphite, the die having a tamped boron nitride liner. This material is also used for protecting the ends of the boron-nickel compact. The temperature is raised to 1,950°C by means of a high-frequency induction heater and maintained for 5 minutes whilst a load of 4,100 p.s.i. is applied. After cooling, the pressed material is extracted by pressing out at a pressure of a few p.s.i., the small amount of boron nitride adhering to the compact being readily removed with an abrasive hand tool. Machining to close tolerances can then be

achieved by diamond milling. Fig. 4 shows two compacts produced by this technique.

BORON-CONTAINING MATERIALS

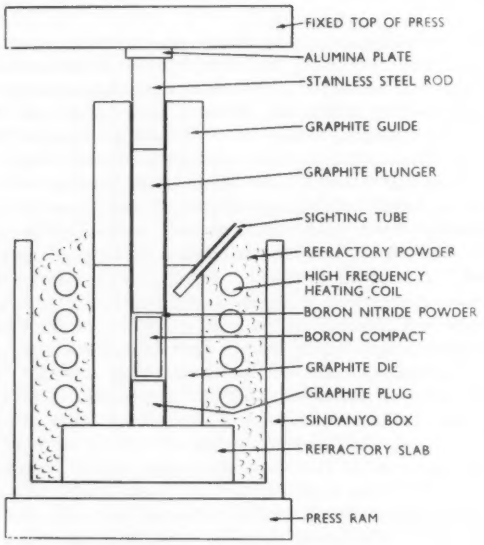
Boron is rarely required in reactor technology in the elementary form. A fairly concentrated form is sometimes needed for control materials, but where the element is used for shielding purposes the material needs usually to be only fairly dilute in boron.

Boron Steels

Steels containing several per cent. of boron were first used for control purposes in this country at Windscale and Calder Hall, prior to which our experience of boron steels was largely confined to those containing much smaller quantities of boron added with a view to increasing hardenability. The development of the high boron steels used in these reactors has been described by Middleham[28] *et al.* They are relatively pure iron-boron alloys (constituents such as manganese would be undesirable at any appreciable level due to the intense γ-radiation induced in a neutron flux), with aluminium added to assist working. For boron contents between 2 and 4.75% there was found to be a critical range for the aluminium content within which the alloys could be forged and rolled; at higher boron levels the Fe-B-Al alloys were unforgeable but castings were successfully produced up to about 6% boron (Fig. 5).

The boron additions were made in the form of a ferro-boron alloy containing about 20% boron and produced by aluminium reduction of boric and iron oxides. Graphite moulds were adopted for the production of ingots, forging of which was carried out at 1,090 to 850°C; rolling of the forgeable steels was possible in a rather lower temperature range beginning at 1,050°C. Extrusion at about 1,000°C could be successfully carried out on the steels containing up to 3.8% boron. Machining of those containing up to 2% boron was found to be easy but became more difficult at higher concentrations, carbide tools being essential at 4% but the steels becoming virtually unmachinable at 5%.

Fig. 3.—Hot-pressing unit for production of boron-nickel compacts.



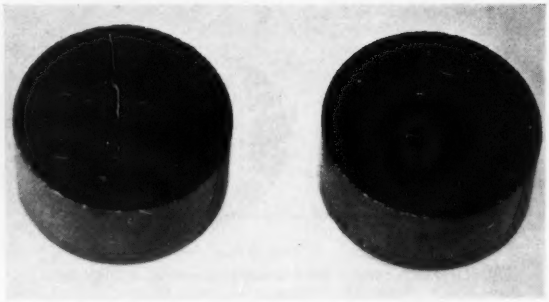


Fig. 4.—Boron-nickel compacts produced by the techniques shown in Fig. 3.

By strict control of the casting temperature, castings could be produced in silica and sand moulds; thus tubes with a wall thickness of $\frac{1}{4}$ in. were cast to a very high standard of dimensional tolerance and surface finish in resin-bonded silica moulds produced by the shell moulding process. The steels were extremely fluid and were successfully cast at temperatures near 1,400°C. Brazing and welding offered no special problems.

Table C1 shows typical compositions of the cast and hot-worked steels, and some of their physical properties are listed in the Data Sheet. (These steels are the subjects of British patent applications and foreign patents.) With regard to mechanical properties the steels are characterized by poor ductility and low impact properties. They are,

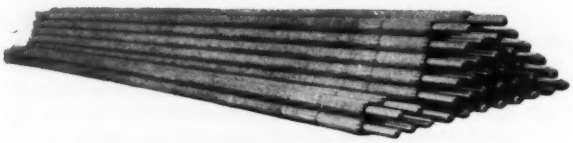


Fig. 6.—Complete control rods of the type used at Calder Hall.
(Courtesy *Journal of the Iron and Steel Institute*)

therefore, enclosed in a low-colbalt, austenitic stainless steel sheath which acts as the structural member, and which serves also to contain any material abraded or corroded from the absorber.

Some of the complete control rods of the type used at Calder Hall are shown in Fig. 6. The boron steel within the sheaths is in the form of tubular inserts. Those at the bottom have a wall thickness of $\frac{1}{4}$ in. and contain 4% boron, whilst the upper ones have an $\frac{1}{8}$-in. wall and contain 3% boron. The 4% inserts were cast and centreless ground; the 3% tubes were extruded and finished by grinding. Mechanical soundness was checked by drop tests.

Harris[29] has described the addition of substantial amounts of boron to stainless steel. It was found that approximately the same percentage of boron could be added to both ferritic and austenitic stainless steels without too drastic an effect on the forgeability and mechanical properties. About 2.5 to 3% could be tolerated by 13% chromium and austenitic stainless steels before they became unforgeable. Mechanical properties given by Harris for both mild and stainless steels containing various percentages of boron are shown in Table C2.

Information on the Fe-B equilibrium diagram is conflicting. That proposed by Wever and Mueller[30] is shown in Fig. 7. However, it has been pointed out by Middleham[28]

Nuclear Engineering

DATA SHEET

No 12. Boron

and Boron-containing materials

A. ELEMENTARY BORON

Symbol	B
Atomic number	5
Atomic weight	10.82
Naturally occurring isotopes	10, 11
Other isotopes	8, 9, 12
Cross-section of natural element for thermal neutrons	(barns/atom)
(a) Scattering	4 ± 1
(b) Capture	755 ± 1
Density	2.33 g/cm³
Melting point (20)	ca. 2,000 to 2,075°C
Boiling point	ca. 2,530°C
Vapour pressure	Table A1
Heat of vaporization (21)	75 kcal/g at.
Heat capacity (C_P) at T°K (22)	$1.54+0.0044T$ (273<T<1,200) cal/°C, g at.
Knoop hardness (K_{100}) (45)	2,500
Coeff. of thermal expansion (from 20 to 750°C)	8.3×10^{-6}/°C

TABLE A1

Vapour Pressure of Boron (21)

Temp. °K	Vapour pressure (atmospheres)
ca. 1,500	10^{-6}
1,600	10^{-5}
1,750	10^{-4}
1,900	10^{-3}
2,150	10^{-2}
2,800	1

B. B_2O_3 AND BORON HALIDES

Melting and boiling points and free energies of formation are shown in Fig. X and Table B1.

TABLE B1

Melting and Boiling Points of Boron Halides and Oxide

	M.Pt. (°K)	B.Pt. (°K)
BF_3	144	172
BCl_3	166	286
BBr_3	227	363
BI_3	323	483
B_2O_3	723	1,773

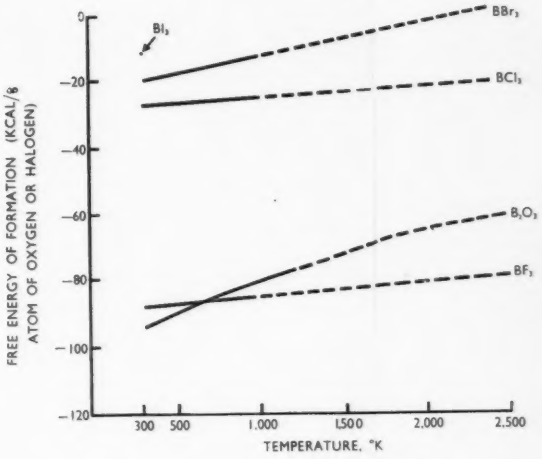


Fig. X.—Free energies of formation of boron halides and B_2O_3.

TABLE A2

Composition of some Commercially available Grades of Elementary Boron (Borax Consolidated, Ltd.)

Description	Form	Typical analysis (wt. %)							
		B	Mg	Al	Mn	Fe	Si	O	H
Crystalline Boron Type 1 (8)	Hard irregular lumps or powder down to −100 BSS	99.15	0.42	0.14	0.13	0.11	0.05		
Crystalline Boron Type 2 (8)	Powder 1 to 3 μ	99.6	Tr.	Tr.	Tr.	0.2 max.	0.2 max.	0.1 max.	0.05 max.
Amorphous 90–92A (9)	Powder ultimate particle size 0.3 to 1.5 μ	91.6	3.9			0.12	0.1	Difference?	
Amorphous 95–97A (9)	Powder ultimate particle size 0.3 to 1.5 μ	96.0	0.9			0.14	0.1	Difference?	

TABLE A3

Composition of some Commercially available Grades of Elementary Boron (Borax and Chemicals, Ltd.)

Description	Form	Typical analysis (wt. %)						
		B	Mg	Na	Moisture	Water soluble B	Insol. in H_2O_2	N
"Trona" Amorphous standard 90–92% (10)	Powder av. particle size 1.0 μ max.	90 to 92	4 to 6		0.5 max.	0.2 to 0.3	1.0 max.	0.1 to 0.2
"Trona" Amorphous Mg reactive (10)	Powder av. particle size 1.0 μ max.	84 to 90	4 to 12		0.5 max.	0.5 max.	1.0 max.	0.1 max.
"Trona" Amorphous high Magnesium (10)	Powder av. particle size 1.5 μ max.	86 to 88	10 to 13		0.5 max.	0.5 max.	3 max.	0.1 max.
"Trona" Amorphous Na Reactive (10)	Powder av. particle size 1.0 μ max.	65 to 75	6 to 12	7 to 13	0.5 max.	1.0 max.	1.0 max.	2 max.

C. BORON STEELS

Chemical properties .. .. Table C1
Physical properties .. .. Table C2

TABLE C1

Typical Analyses of Production-scale Boron Steels of the Type Developed for Control in Windscale and Calder Reactors (28)

Steel No.	C	Si	Mn	B	Al
		Cast Steels			
1	0.16	0.23	0.13	4.05	0.03
2	0.09	0.38	0.21	4.14	0.12
3	0.10	0.43	0.14	4.20	0.53
4	0.11	0.45	0.18	4.25	0.03
5	0.10	0.44	0.23	4.29	0.35
6	0.09	0.52	0.19	4.30	0.02
7	0.11	0.42	0.23	4.40	0.10
8	0.15	0.43	0.21	4.42	0.05
9	0.08	0.46	0.27	4.58	0.11
10	0.12	0.60	0.31	5.03	0.29
		Hot-worked Steels			
11	0.04	0.20	0.10	1.75	0.54
12	0.07	0.47	0.26	1.85	0.04
13	0.10	0.62	0.26	1.90	0.02
14	0.05	0.70	0.30	1.96	0.03
15	0.05	0.48	0.13	2.20	0.44
16	0.07	0.75	0.40	2.64	0.21
17	0.06	0.31	0.49	3.15	1.75
18	0.08	0.46	0.24	3.24	0.89
19	0.11	0.48	0.30	3.40	0.61
20	0.09	0.53	0.26	3.62	0.76
21	0.11	0.56	0.29	3.62	0.76
22	0.10	0.52	0.27	3.69	0.76
23	0.11	0.48	0.30	3.79	0.61
24	0.09	0.53	0.26	3.81	0.71

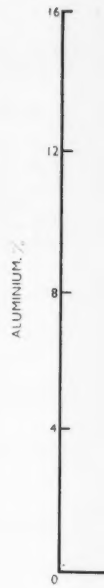


TABLE C2

Physical Properties of Boron Steels of General Composition in C1 (28)

Property	Temp. (°C)	Boron content (wt. %)		
		2	3	4
Thermal expansion ($\times 10^{-6}$/°C)	20–100	10.0	10.0	9.5
	–200	11.0	10.3	10.0
	–300	11.5	10.6	10.4
	–400	11.9	10.9	10.8
	–500	11.4	11.2	11.2
	–600	11.8	11.5	11.6
	–700	13.0	11.8	11.8
	–800	13.3	12.0	12.0
	–900			12.5
	–1,000			13.0
Electrical conductivity (microhm/cm³)	0	24.9	37.2	39.9
	26, 24.2, 24	26.4	39.2	42.7
	100	30.9	45.6	50.6
	200	38.7	54.6	61.5
	300	47.6	63.6	72.3
	400	57.4	73.2	83.3
	500	69.3	84.1	94.3
	600	81.9	95.5	106.5
	700		107.5	119.6
	800			129.4
Specific magnetism (S.C.I.=100)	20	90.9	75.6	72.2
Specific gravity	20	7.72	7.44	7.36
Specific heat (cal/g, °C)		0.110	0.124	0.125
Thermal conductivity (cal/cm, sec, °C)	70–100		0.096	

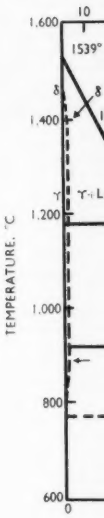


TABLE C3

Effect of Boron on Mechanical Properties of mild and sta

Chemical composition (%)				
C	Ni	Cr	B	Others
0.1	—	—	0	0
0.1	—	—	1	0
0.1	—	—	2	—
0.1	—	—	3	—
0.05	1	14	2.4	Al 0.6
0.15	14	19	0	Nb 1.5
0.15	14	19	1	Nb 1.5
0.15	14	19	2	Nb 1.5
0.03	7	17	1	Al 1.0

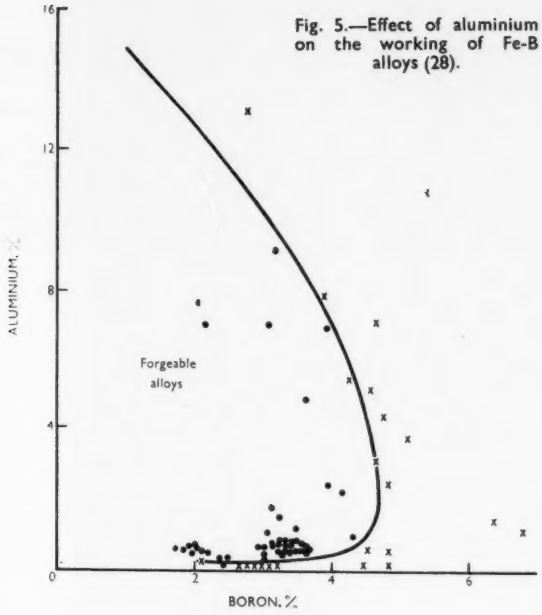


Fig. 5.—Effect of aluminium on the working of Fe-B alloys (28).

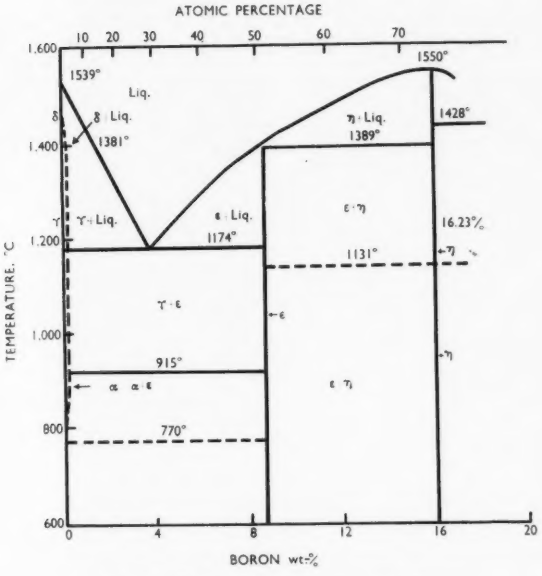


Fig. 7.—Fe-B equilibrium diagram (30).

of mild and stainless Steels (29)

	Mechanical properties		
Others	0.1% Proof stress (tons/in²)	U.T.S. (tons/in²)	Elongation (%)
0	(7)	19	50
0	8	27	26
—	16	37	9
—	20	49	4
Al 0.6	—	60	5
Nb 1.5	13.5	38	52
Nb 1.5	14.4	43	25
Nb 1.5	18.8	48	8
Al 1.0	78	95	8

D. BORON CARBIDE

Density 2.5
Melting point .. .. ca.
Heat capacity (C_P) at T°K (22)
$22.99+0.0054T-0.000\,107T^{-2}$ $(298<T<1{,}373)$ cal/°C,
Coeff. of thermal expansion (from 20 to 800°C) (45)
$4.5\times$
***Thermal conductivity** (3) .. .. T
Crystal structure .. .. Rhomb
Knoop hardness (K_{100}) .. ..
Strength, binding (6) 35,0
Strength, compression (6) 414,0

* Density 2.50 g/cm³

TABLE D1

Thermal Conductivity of Boron Carbide

Temperature °C	Thermal conductivity cal/cm, sec, °C
100	0.29
300	0.22
500	0.18
700	0.155

E. BORAL

The following data (46) refer to sheet comprised of $\frac{1}{8}$ in. th
of a suspension of B_4C in aluminium, clad on each side with alu
to give a total thickness of $\frac{1}{4}$ in.

Composition .. .. T
***Thermal neutron attenuation factor** .. ..
***Density** 2.5
†Tensile strength .. .. T
†Elongation .. ..
†Shear strength 8,2
†Thermal conductivity .. .. T

* Core material containing 35 wt.% B_4C.
† Core material containing 50 wt.% B_4C.

TABLE E1

Composition of Boral (35 wt. % B_4C)

	Wt. %	mg/cm²
Boron	15.7	254.0
Carbon	4.3	71.0
Aluminium	80.0	1,303.0

TABLE E2

Variation in Tensile Strength of Boral (50 wt. % B_4C) with Irradiation

nvt	Tensile strength p.s.i.
0	5,000
3.1×10^{18}	6,335
4.8×10^{18}	7,500
1.2×10^{19}	5,650
2.6×10^{19}	5,500

TABLE E3

Thermal Conductivity of Boral (50 wt. % B_4C)

Temperature °F	Thermal conductivity B.t.u./h, ft, °F
200	25.0
450	19.2
500	19.0

F. METAL BORIDES

Chemical and physical properties .. .. Table F1

TABLE F1

Composition and Properties of Commercially Available Metal Borides (35)

Boride	Chemical analysis (wt. %)									Density (g/cm³)		Melt
	Technical grade*				Chemically pure†					Measured	X-ray	
	Metal	B	Fe	C	Metal	B	Fe	C	Cl res.			
TiB_2 ..	68.4±0.3	31.0±0.2	0.2 max.	0.1 max.						4.4	4.53	2,90
ZrB_2 ..	80.6±0.2	19.1±0.1	0.2 max.	0.1 max.						6.2		3,00
VB_2 ..	70.0±0.3	29.6±0.3	0.2 max.	0.1 max.	70.2±0.1	29.8±0.1	<0.05	—	<0.1	5.0	5.1	2,10 (techni
												2,40 (chemic
NbB_2 ..	81.0±0.2	18.6±0.2	0.2 max.	0.1 max.	81.0±0.1	19.0±0.1	<0.05	—	<0.1	6.9	7.21	2,90
NbB ..	89.4±0.3	10.2±0.2	0.1 max.	0.1 max.	89.5±0.1	10.5±0.1	<0.05	—	<0.1	7.5		
TaB_2 ..	89.0±0.2	10.6±0.1	0.1 max.	0.1 max.	89.3±0.1	10.7±0.1	<0.05	—	<0.2	11.7	12.6	3,10
TaB ..	94.1±0.2	5.5±0.2	0.1 max.	0.1 max.	94.3±0.1	5.7±0.1	0.05		<0.2	14.0	14.9	
CrB_2 ..	70.4±0.3	29.0±0.3	0.2 max.	0.1 max.						5.6	5.6	1,85
CrB ..	82.7±0.3	16.7±0.3	0.1 max.	0.1 max.						6.05	6.11	1,55
Cr_3B_2 ..	87.3±0.3	12.1±0.2	0.1 max.	0.1 max.						6.1		1,96
MoB_2 ..	81.3±0.3	18.1±0.3	0.2 max.	0.1 max.	81.6±0.1	18.4±0.1	0.05	—	<0.1	8.5	9.0	2,10
MoB ..	90.0±0.3	10.0±0.2	0.2 max.	0.1 max.	89.9±0.1	10.1±0.1	0.05	—	<0.1	8.5	8.77	2,18
W_2B_5 ..	87.0±0.3	12.5±0.3	0.2 max.	0.1 max.	87.2±0.1	12.8±0.1	0.05	—	<0.1	11.0	13.1	2,30
WB ..	94.3±0.2	5.5±0.2	0.1 max.	0.1 max.	94.4±0.1	5.6±0.1	0.05	—	<0.1	15.1	16.0	2,86
W_2B ..					97.1±0.1	2.9±0.1				16.5		2,77

* Av. particle size 5 to 10 μ. † Av. particle size 10 to 50 μ.

TABLE F2

Transverse Rupture Strength of Uncemented Zirconium Boride Compacts (39)

Sintering temperature (°C)	Time at sintering temperature (sec)	Transverse rupture strength at room temperature (p.s.i.)
2,550	30	8,000
	60	11,000
	180	11,500
2,800	30	14,500
	60	19,000
	180	21,000
2,865	30	22,300
	60	22,800
	180	25,100

G. BORON—CONTAINING GRAPHITE

Physical properties .. .. Table G1

TABLE G1

Properties of Morganite Borated Graphite (41)

Property	Temperature (°C)	
Average apparent density (g/cm³)	R.T.	1.48
Coefficient of thermal expansion .. .. (×10⁶/°C)	R.T. −100	3.01
	−200	3.04
	−300	3.09
Thermal conductivity (cal/cm, sec, °C) .. (Material of apparent density 1.44 g/cm³)	100	0.059
	200	0.056
	400	0.050
	600	0.043
Ultimate compressive strength .. .. (tons/in²)	R.T.	1.48

Table F1

l Borides (35)

nsity (g/cm³)		Melting pt. (°C)	Micro-hardness (kg/mm²)	Specific resistance at 20°C (microhm-cm)
ured	X-ray			
4	4.53	2,900±80	3,400	15.2
2		3,000±50	2,300	9.2
0	5.1	2,100±60 (technical grade) 2,400 (chemically pure)	2,100	16.0
9	7.21	2,900±100	2,600	32.0
5				64.5
7	12.6	3,100	2,500	68.0
0	14.9			100.0
6	5.6	1,850±50	1,800	21.0
05	6.11	1,550±50		64.0
1		1,960±50		
5	9.0	2,100	1,280	45.0
5	8.77	2,180	1,570	50.0
0	13.1	2,300	2,600	21.0
1	16.0	2,860		
5		2,770		

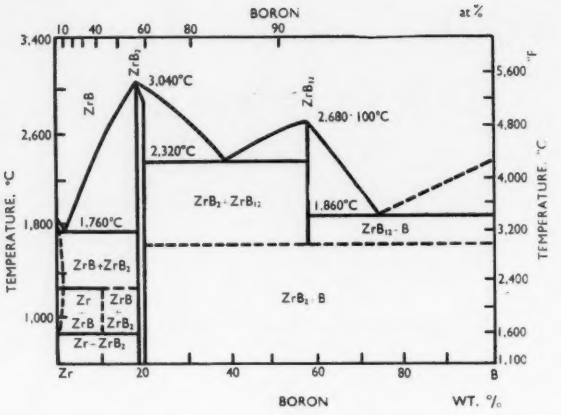


Fig. 8.—Zr-B equilibrium diagram (37).

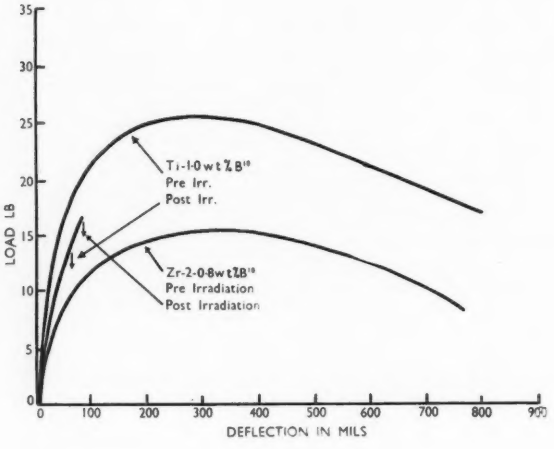


Fig. 10.—600°C bend tests on boron alloys after irradiation (42).

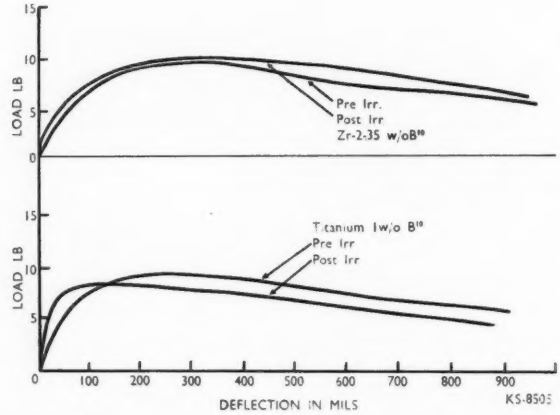


Fig. 11.—600°C bend tests on boron dispersions after irradiation (42).

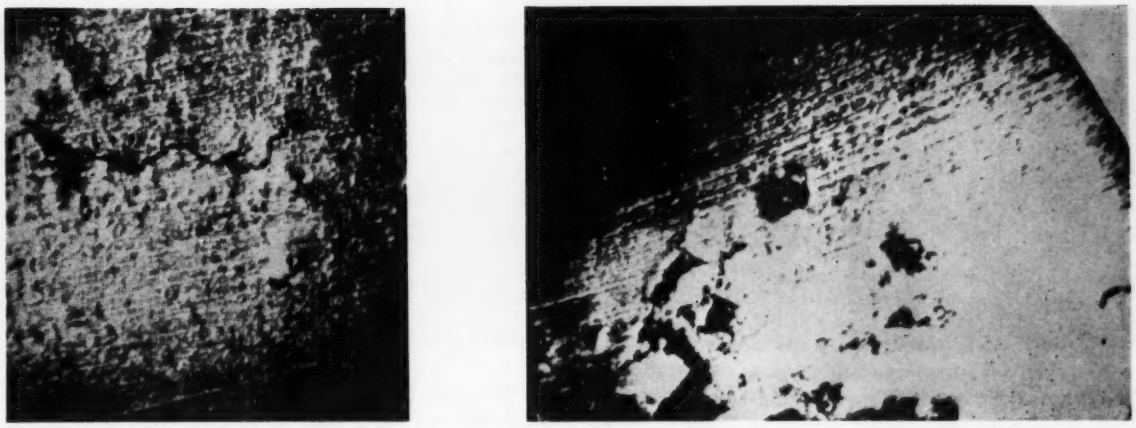


Fig. 9.—Micrographs showing cracks formed in Zr—0.8 wt.% B-10 alloy (left) and Ti—1 wt.% B-10 alloy irradiated to 40% burn-up of B-10 atoms (42).

et al. that, although usually accepted as the most reliable this diagram was deduced using impure materials, and these authors reproduce additional alternative versions. Separate studies of the solubility of boron in α- and γ-iron have also been reported. Thus McBride[31] *et al.* found that the solubility in α-iron varied from 0.0004% at 710°C to 0.082% at 906°C; in γ-iron the range extended from 0.0021% at 906°C to 0.0210% at 1,140°C.

Boron Carbide

So far as production and fabrication are concerned boron carbide shows distinct advantages over elementary boron. It may be prepared either by vapour phase deposition (e.g., by passage of a 1 : 1 mixture of BCl_3 and hydrogen over a graphite rod heated to 1,800°C) or by electrothermal methods. The structure is rhombohedral and contains a continuous three-dimensional network of boron atoms. The density is 2.51 g/cm³. According to work at the Norton Company[6] there is a sharp limit to the homogeneity range at 20 at.% carbon, any excess appearing as graphite. There is, however, some solubility of boron in B_4C, the boron apparently replacing carbon atoms in the lattice rather than being accommodated interstitially. The upper limit to this solubility was not established, but free boron was detected in preparations having mol ratios in the range 7-10.

Some of the physical and mechanical properties of the material have been collected in the Data Sheet. In the massive form it is hard and brittle but has appreciable compressive strength. From a chemical point of view it is relatively inert, being dissolved only by fused alkalis. At high temperatures however, it reacts with many metals or their carbides, converting them into borides. For material prepared by vapour phase deposition Powell[7] states that in air only superficial oxidation occurs at temperatures up to 800 to 1,000°C due to the formation of a protective oxide glaze; the attack becomes appreciable at 1,100 to 1,200°C and rapid at 1,500 to 1,600°C.

The material can be fabricated in a wide range of densities, the available techniques being described elsewhere[6] in some detail. Powdered boron carbide can be packed to a maximum density of 1.9 g/cm³. Densities of up to 2.3 g/cm³ (corresponding to boron density of 1.8 g/cm³) are obtained either by cold moulding and sintering or by hot-pressing. Parts fabricated in this way can be finished to close tolerances by surface grinding. Thermal shock properties can be improved by bonding with certain transition metals or their carbides, and in general the development of boron carbide parts with properties suitable for specific applications should be possible by the exploitation of metallic and non-metallic bonding materials.

Boral

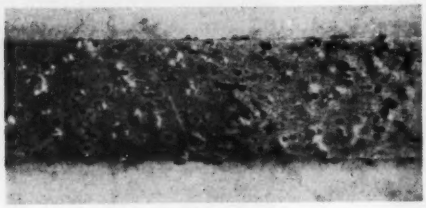
The development of this material for thermal shields at Oak Ridge has been described by McKinney and Rockwell[32] and by Kitzes and Hullings[33]. It consists of a suspension of boron carbide in aluminium which is clad in aluminium. A total thickness of ¼ in. is usual with the core about ⅛ in. thick and containing 35 wt.% B_4C; concentrations of up to 50 wt.% B_4C can be achieved for the core material. Properties of the material are shown in the Data Sheet; creep-rupture data obtained by Saller[34] *et al.* at BMI are given elsewhere. It has a density of about 2.5 g/cm³, can be welded by the heli-arc process and easily cut by shearing. An alternative material, boraxal, consists of a mixture of B_2O_3 and aluminium; it is slightly cheaper than boral but its properties are somewhat inferior.

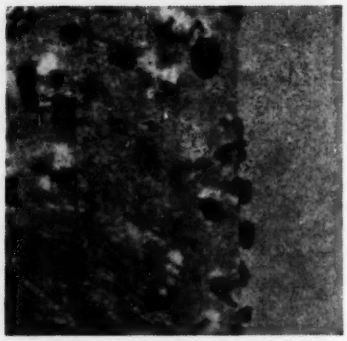
Borides

Investigations of metal-boron systems have led to the establishment of the structure, properties and method of fabrication of a number of borides. This work was stimulated by the search for high-temperature high-strength materials for use in the aircraft industry, but borides are likely to find application in nuclear engineering also because they provide a most useful form of boron. Their main application is likely to be in the production of fabricated parts with a high boron density.

A large number of these borides are now commercially available. These and some of their properties are listed[35] in the Data Sheet. They may be prepared by a variety of methods, including direct combination by melting or sintering, reduction of B_2O_3 by the metal, reaction of the metal or metal oxide with boron carbide with or without the addition of B_2O_3, fused salt electrolysis and vapour phase deposition. Their crystal structures have been established largely by the work of Keissling, and show considerable diversity. Only the diborides and the closely related structures of Mo_2B_5 and W_2B_5 can be regarded as simple. Here the metal atoms form a hexagonal lattice and the boron atoms are arranged in the form of nets with hexagonal meshes, each boron atom being placed at

Fig. 12.—"Warts" on the surface of a Ti B dispersion after irradiation (42).





the centre of a trigonal prism of metal atoms. At least seven other types of structure have been found[36] for the metal borides. In every case the important characteristic is the tendency for the boron atoms to be closely linked in chains, sheets or three-dimensional networks.

In only a few cases have the phase diagrams of these systems been investigated in any detail, but it is known that in many instances (e.g., in the systems formed by boron with Mo, Ta, W and Nb) boride phases are stable over a range of composition. With regard to thermal stability, the most stable borides of the Group IV transition metals appear to be the diborides, whilst in Group VI the monoborides appear to be the most stable; for the Group V metals the stabilities seem to be about equal. Powell[7] *et al.* have discussed the air oxidation of some of these borides as formed by vapour deposition.

The Group IV borides appear to be more oxidation-resistant than those of the fifth or sixth Group, zirconium boride being fairly resistant up to 1,300 or 1,400°C, but vanadium boride oxidizing at an appreciable rate at 1,000 to 1,100°C for example. The oxide films produced on Zr, Ta and W borides tend to be porous, that on vanadium boride being a low-melting glass. A number of borides are decomposed by ammonia with the formation of nitrides. However, they are fairly resistant to attack by the more common chemicals, though the borides of manganese, the iron group metals and the alkaline earth and rare earth metals are soluble in oxidizing acids.

The following information relevant to the Zr-B system and in particular ZrB_2 will illustrate further the properties and potentialities of these systems. The phase diagram (Fig. 8) was deduced by Glaser and Post[37], and indicates the existence of three borides; ZrB, ZrB_2 and ZrB_{12}, of which only ZrB_2 shows reasonable stability. It has a Rockwell "A" hardness of 87 to 89 and an electrical conductivity at 20°C of 9.2 microhm-cm; the thermal conductivity at this temperature has been reported[38] to be 0.055 cal/cm^2, sec, °C. Pressure sintering at 1.3 ton/in.^{2} to densities of up to 95.5% theoretical have been achieved by Glaser[39]. The effect of time and temperature on the transverse rupture strength of the compacts is shown in Table F2, indicating a maximum room temperature value of 25,100 p.s.i. "Borolite," a marketed form of ZrB_2 shows good thermal shock properties and as a container for molten metals causes only slight contamination.

Further exploitation of borides may come from work on the combination of these compounds among themselves or with other refractory materials such as carbides and nitrides. Isomorphous borides may be expected to form solid solutions providing the radius ratio of the metal atoms is favourable, and this has been observed in a number of cases. In this way the β-form of MoB can be stabilized by bringing it into solid solution with the isomorphous CrB, at least 50 wt.% of MoB being soluble. A number of compounds have been established[40] in the pseudo-binary systems, including $MoCoB_2$, Mo_2NiB_2, Mo_2FeB_4, Mo_2CoB_4 and Mo_2NiB_4.

Boron-containing Graphite

This material finds application as a neutron shield, one of its advantages being the very low residual activity exhibited by it even after prolonged irradiation. The boron is conveniently introduced into the graphite by impregnation with a suitable compound of the element. Some of the physical and mechanical properties of Morganite Borated Graphite[41] manufactured by the Morgan Crucible Co., Ltd., are shown in the Data Sheet.

EFFECT OF REACTOR CONDITIONS

The lithium and helium atoms which result from the (n, α) reaction undergone by B^{10} are both large by comparison with the parent atom. Lattice strains must therefore be associated with the reaction, and there is also the possibility of the helium being released to form pockets of gas which build up to a pressure sufficient to cause further physical damage. The parallel with the damage resulting

Le Bore

Parmi les matériaux d'obtention facile, le bore est peut-être celui qui s'emploie à plus grande échelle pour l'absorption des neutrons aux fins de protection et de contrôle. Le présent article traite de la venue et de l'extraction de l'élément ainsi que de la séparation de l'" isotope-10." On y étudie lés propriétés nucléaires, physiques, mécaniques et chimiques du bore et des matériaux contenant du bore tels que l'acier au bore, le graphite au bore et divers borures, ainsi que les effets de l'irradiation dans un réacteur.

Bor

Von allen leicht beschaffbaren Werkstoffen ist wahrscheinlich Bor das am meisten überall verwendete Material zur Absorbierung von Neutronen, für Schutzwandungen und für Kontrollzwecke. Der Aufsatz behandelt das Vorkommen und die Extraktion des Elements und die Separation des Isotops 10. Die nuklearen, physikalischen, mechanischen und chemischen Eigenschaften des Bors und der Bor enthaltenden Werkstoffe wie Borstahl, Borgraphit und der verschiedenen Boride werden besprochen, ferner die Wirkungen der Bestrahlung in einem Reaktor.

Boro

De los materiales que hay fácilmente disponibles, el boro es quizás el de más extenso uso para absorción neutrónica para blindaje protector y propósitos de control. Este artículo cubre la ocurrencia y la extracción del elemento y la separación del " 10-isotopo." Las propiedades físicas, mecánicas y químicas del boro y de materiales con contenido de boro, tales como el acero borónico, grafito borónico y diversos boruros son tratadas en este artículo, así como también los efectos de irradiación en un reactor.

from uranium fission when the latter involves production of a gaseous atom is evident, but in the case of boron the problem is more severe inasmuch that a gaseous atom is produced in every fission, and that the relative volume increase is larger. The range of the fission fragments is less, but is still sufficient for the damage to extend to a matrix material. For the relatively low doses which shielding materials are required to withstand such effects are unlikely to be serious, but in the case of control materials it is clear that significant problems must arise if high burn-up is required.

There is little published work on radiation effects in boron and boron-containing materials, but their general nature can be gauged from the experiments of Anderson and Dunning at KAPL[42] on alloys and dispersions of boron. It was found that any appreciable burn-up resulted in growth and embrittlement. Cracks thus formed in Zr-0.8 wt.% B^{10} and Ti-1 wt.% B^{10} alloys after irradiation to 40% burn-up of B^{10} atoms are shown in Fig. 9. The growths observed were of the order of 3 vol.% per atom % burn-up. Fig. 10 shows the results of bend tests obtained at 600°C on Zircaloy 2-0.8 wt.% B^{10} irradiated to 1.5 total atom % burn-up and Ti-10 wt.% B^{10} irradiated to 1.6 total atom % burn-up. The total nvt values were calculated to be 4×10^{20} and 8×10^{20} respectively. A high degree of embrittlement is evident.

The behaviour of boron-stainless steel alloys was found to be similar when irradiated under comparable conditions. Boron dispersions in these materials formed by powder metallurgy techniques retained some ductility in the 600°C bend test (Fig. 11), although increasing the boron concentration to about 10 vol.% brought a return of the severe embrittlement shown by the alloys. At the lower concentrations, however, the dispersions showed no gross distortion, but pimples or warts appeared on the surface. These are illustrated in Fig. 12, which relates to the Ti-B dispersion.

Radiation damage in hot-pressed boron carbide was investigated[43] by Valovage. Extensive physical damage occurred, beginning with loss of hardness and cracking after low burn-up and increasing until complete granulation occurred after 36% burn-up of B^{10} atoms; at this burn-up and after heating to 1,000°F a maximum of 8% of the theoretical quantity of helium was released. The material was more extensively damaged when irradiated in sodium than in vacuo.

Further work on boron-stainless steel dispersions has been described[44] by Eichenberg. Specimens were prepared by mixing boron and stainless steel powders and extruding at 980 to 1,010°C using an approximately 16 : 1 reduction. Specimens for impact and tensile tests were annealed at 1,065°C and slow cooled. Irradiation was carried out in Zircaloy 2 capsules filled with sodium/potassium. The compositions studied included 1 wt.% B^{10}, 2 wt.% B^{10} and 5 wt.% natural boron and the irradiations were carried out to a maximum total nvt of 10^{21}. Again no gross dimensional changes were observed, but the hardness increased by approximately 175 DPN and was independent of exposure in the range studied. The average elongations of the 1 and 2 wt.% B^{10} samples prior to irradiation were 18.8 and 8.1% respectively, and their average ultimate strengths 88,000 and 84,000 p.s.i. The maximum elongation for both compositions after irradiation was 0.6%, indicating that almost complete embrittlement had occurred even at the lowest dose studied (0.8×10^{20} nvt). The ultimate strength of these specimens appeared first to increase with exposure and subsequently to decrease.

A full interpretation of such results is impossible at this stage. Further experimental work is required for their elucidation and also to guide the development of materials with improved radiation resistance properties.

CONCLUSIONS

It is evident that boron is now available in a sufficiently wide variety of forms to meet most of the present and future requirements for neutron absorbing materials. This fact, coupled with the possibility of further improving their absorption properties by removal of the 11-isotope, suggests that only the radiation damage properties of boron-containing materials are likely to lead to their displacement as the most convenient type of material for control and shielding purposes. At the present time it is not possible to see the extent to which these properties can be improved, and it may, therefore, be that where high burn-up is required the high cross-section rare earths may supersede boron. In this connection their increasing availability and decreasing cost are not without significance.

ACKNOWLEDGMENTS

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ARGONNE LOW POWER REACTOR

Development of the BORAX Experiments Dedicated on December 2

THE Argonne Low Power Reactor is a direct-cycle boiling water unit envisaged as a source of electrical power (200 kW) and space heating (approx. 400 kW) for isolated situations such as, say, a radar station in the Arctic, where conditions are severe and access is difficult except by air. In such a situation, the increased plant cost over a simple diesel station would be offset by the possibility of obtaining three years' operation from about 2 cwt of core material, instead of some 1,500,000 gal of fuel oil. Other site conditions anticipated were temperatures of 60°F to −60°F, or permanent frost, scarcity of water, and winds up to 125 m.p.h. Transport economy is even considered to the extent of using local gravel for shielding purposes.

The actual plant design specified a 300 kW turbo-alternator and a space-heating output of 1.3×10^6 B.t.u./min. The reactor overall heat rating is 3 MW.

Particularly interesting design features of this plant are the air-cooled condenser unit, and the widespread use of an experimental aluminium-nickel alloy, developed by Argonne and known as X-8001, first used for fuel element cladding in BORAX IV. A new bonding technique has also been developed for fuel element fabrication.

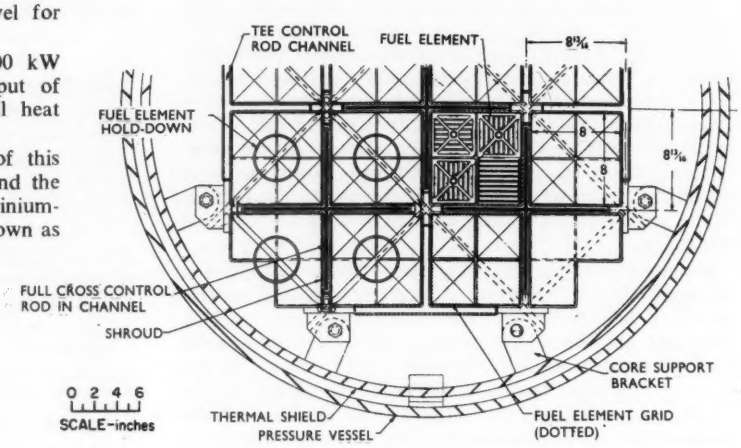


Fig. 1.—Cross-section of core showing location of cross and tee control rods and arrangement of fuel element enclosures. (Dimensions are in inches.)

Core Design

The construction of the core can be seen from the cross-section (Fig. 1). The core support consists of a horizontal grid of 2½ in. × ½ in. aluminium alloy notched and welded in a "noughts and crosses" pattern, the open ends being closed by additional welded bars. Stanchions of cross- and tee-section, welded at the intersections of the horizontal grid, form the structural skeleton of the core support. Flush-riveted to these are large angle sections 62 in. long formed from sheet 16 in. wide and 5/32 in. thick making a series of hollow-walled vertical cells of 8 in. square cross-section. The inner cells are pierced by equally spaced 2 in. holes to assist water circulation and ensure proper cooling for the control rods. The outer enclosure is not perforated. Each of 12 square cells provides accommodation for four fuel elements; the four corner cells each accommodate three elements. The hollow walls provide enclosures for five control rods of cross-section and four of tee-section.

The shape and general proportions of the core were the result of experimental work in the BORAX series of reactors which determined the proportions of the fuel elements. Another important factor was the proportion of voids in the core. For a low metal/water ratio, voids increase reactivity; for a high metal/water ratio reactivity is reduced by void formation. The ratio decided upon for the cold condition was 0.5. The reactivity controlled by steam voids is approximately 1.5% in the "reference" reactor at 3 MW. The number of fuel elements selected for the reference design was 40; space was provided for a maximum of 59.

The third consideration was the provision of sufficient control rods to give control at all times throughout the core cycle. Five cross rods were selected for the 40-element core and provision made for four tee rods if the maximum loading was used. Rods are not ganged, for safety reasons, and the positions of the rods were dictated by the mechanical limitations of acommodating drive mechanisms.

To reduce control requirements, B^{10} is introduced into the core to provide a burnable poison, and it is anticipated that 10% reactivity will be controlled in this manner in the fresh reactor; the 14% controlled by the five cross rods in the cold reference core is sufficient to cope with the remaining reactivity variation during the operating life of the core. Reactivity variation during lifetime is shown in Fig. 3, the results of a study using first-order perturbation theory.

The variation in effect of the five cross control rods, as a function of the distance travelled into the core, is shown in Fig. 2, the maximum/average differential value of the rod bank being approximately 1.7.

Control rod insertion gives marked distortion of the axial flux distribution (Fig. 4). The fluxes are plotted for two

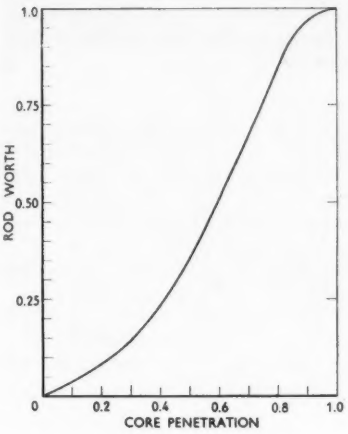
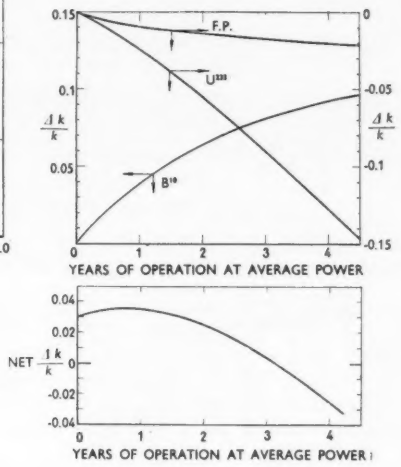


Fig. 2.—(Above) Fractional reactivity effect of the control rods as a function of distance travelled.

Fig. 3.—(Below) Change of reactivity during lifetime due to B^{10}, U^{235} and non-equilibrium fission products. The lower curve shows the net reactivity change.



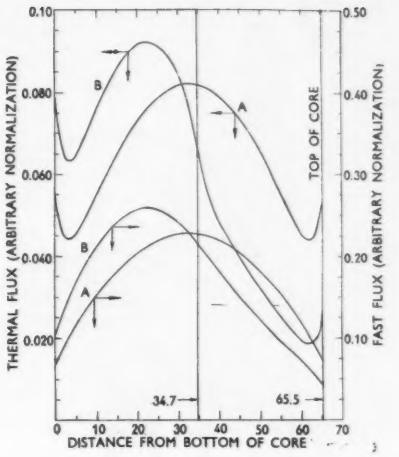


Fig. 4.—(Above) Axial distribution of neutron flux for (A) control rods withdrawn and (B) control rods half-way into core.

cases; with rods fully withdrawn, and half-way in. When the rods are inserted, the neutron flux is compressed into the lower half of the core, the effective boiling length of the core decreases and the mean steam void increases for any given power level. Theoretical analysis predicts a steam void reactivity approximately 50% higher, for the half-way position of the rods.

X-8001 Alloy

The alloy from which the entire core structure is fabricated is one developed by Argonne, and contains nickel (1% by weight) and aluminium 1100, a commercial aluminium alloy containing iron. (The use of Al-Ni alloys for the EBWR was first noted in *Nuclear Engineering* for March, 1957, page 121.)

The X-8001 alloy was first used for fuel element cladding in BORAX IV. It is reported that considerable improvement has been obtained in corrosion resistance with water over about 400°F.

Fuel Elements

Alloy X-8001 is also used for the fuel element assembly which consists of nine fuel plates with bent-over edges to form flanges, spot welded between side plates to form an element of square cross-section.

The fuel plates are of "sandwich" construction. The "meat" is a plate of uranium-aluminium-nickel alloy which is prepared in rectangular form and clad on sides and edges with the X-8001 alloy. This is done by surrounding the fuel plate with side plates and a "picture frame" of X-8001, and bonding the whole into a solid unit.

The bonding process is another Argonne development to eliminate the oxide film that inhibits perfect bonding. After the fuel plate has been cold-pressed into its frame, the aluminium surfaces to be joined are coated with glycerine and sprayed with fine particles of elemental silicon. The plates are then pressed together in heated dies (up to 600°C) with pressures up to 2,000 p.s.i. The sharp particles of silicon puncture the oxide film, and diffuse into the aluminium forming an alloy film which melts at about 570°C and, as pressing continues, is expelled from the interface, carrying the oxide film with it and allowing a complete bond at about 600°C.

The sandwich is then hot-reduced to within about 0.007 in. of finished size and cold-rolled to exact thickness. After ultrasonic analysis the plates are sheared to final dimensions, have their edges bent to form flanges, which are machined to ensure the correct width of coolant channel, and spot-welded to the side plates.

The top fitting consists of an extruded spider section welded to an extruded rectangular piece and carrying a

ALPR TABLES

Table 1. Core Data

Fuel Elements	
Length of element overall	34½ in.
Length of element active	27$\frac{15}{16}$ in.
Lattice (approx.)	4 in.
Cross-section (40 elements)	28 sq. in.
Cross-section (59 elements)	33 sq. in.
Total U^{235} (40 elements)	14.0 kg
Total U^{235} (59 elements)	20.65 kg
Metal/water ratio	0.5
Cross-section of element (9 plates)	3$\frac{1}{8}$ sq. in.
Boron-10 poison per element	0.4 g
Width of fuel plate	3$^{23}/_{32}$ in.
Thickness of fuel plate total	0.120 in.
Thickness of fuel plate meat	0.05 in.
Volume of meat per plate	74 cm³
Weight of aluminium in meat	200 g
Weight of U^{235} in meat	38.9 g
Weight of U^{238} in meat	3.8 g
Control	
No. of + rods	5
Spaces for T rods	4
Spacing	8$\frac{11}{16}$ in.
Length of cadmium section	32 in.
Weight of + rods	49 lb
Weight of T rods	37 lb
Total travel	31 in.
Scram time	<2 sec
Nuclear Data	
Average thermal flux (full power, fresh reactor)	7.5×10^{12} n/cm², sec
Max./average flux ratios (hot fresh reactor)	
Radial	1.6
Control cell	1.3
Axial (control rods out)	1.3
Reactor (control rods out)	2.7
Axial (rods half in)	1.7
Reactor (rods half in)	3.5
Reactivity changes (%)	
Temperature (cold-operating)	−1.5 to −2
Xe+Sm	−3
Steam voids	−1.3 to −2
Xenon override	−1 to −1.5
Neutron lifetime	$4-8 \times 10^{-5}$ sec

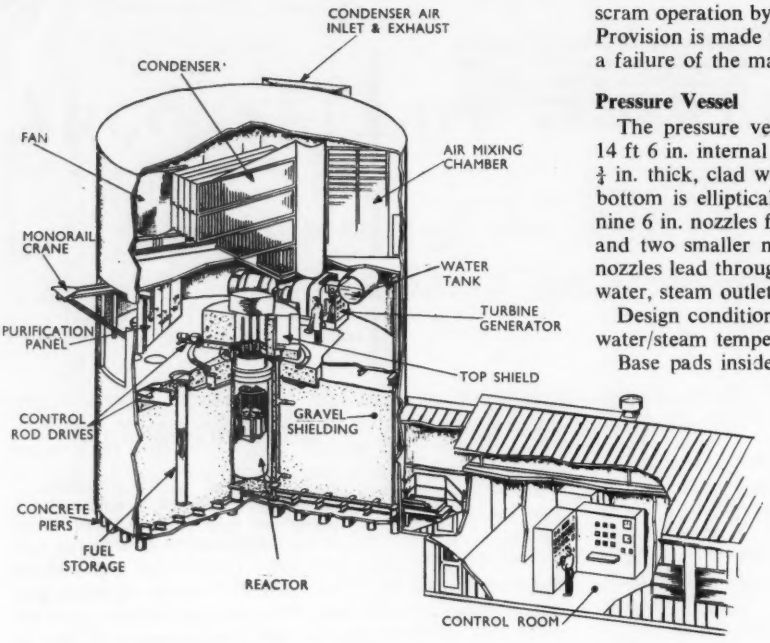


Fig. 5.—(Left) Cut-away drawing of the complete plant and enclosure.

Fig. 6.—(Below) Erecting the roof of the containment tank, showing temporary supporting spider.

stainless-steel pin to act as a gripper for the refuelling mechanism. A spring insert in a machined window each side of the rectangular section provides fuel spacing. A rectangular bottom fitting is provided machined to fit the fuel element support.

On account of the difficulty of fabricating fuel plates containing a fixed amount of poison, use is made of X-800! alloy containing B^{10} in the form of thin strips, one strip being fixed into each fuel element.

Control

The philosophy of the control rods has already been described. The rods are of cadmium and weigh 49 lb each, being 14¼ in. over each pair of arms of the cross. The cadmium is 0.06 in. thick, the alloy cladding 0.08 in. Alloy is also used for the follower material above the absorber section.

A stainless-steel ball-joint end fitting connects the rod to the driving mechanism, which is of the rack and pinion type, enclosed within the reactor, the drive shaft being taken through a labyrinth seal to a ⅛-h.p. motor. A magnetic clutch is provided on each drive to permit scram operation by gravity when the clutch is demagnetized. Provision is made for driving the rod down in the event of a failure of the magnetic clutch.

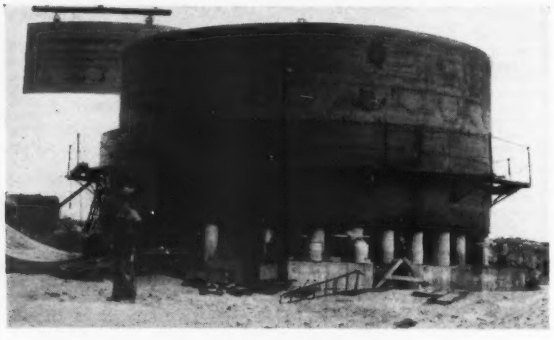


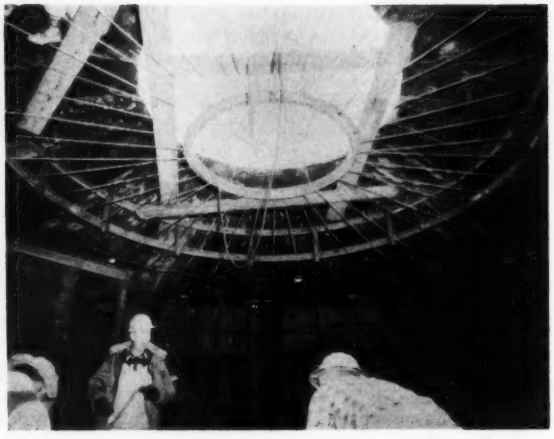
Fig. 7.—The containment tank partly erected on its concrete pillars.

Pressure Vessel

The pressure vessel is 4 ft 6 in. outside diameter and 14 ft 6 in. internal height, of SA 212 Grade B firebox steel ¾ in. thick, clad with 304 stainless steel 3/16 in. thick. The bottom is elliptical, the top plate is flat, 8 in. thick, with nine 6 in. nozzles for control rod drives and access to core, and two smaller nozzles for water level indication. Five nozzles lead through the vessel wall, for feedwater, cooling water, steam outlet, purification and boron injection.

Design conditions for the vessel were 400 p.s.i. at 450°F water/steam temperature and 500°F metal temperature.

Base pads inside the vessel support the internal thermal shield, of ¾ in. stainless steel, which in turn supports the core structure, as can be seen from Fig. 1.



Coolant Circuit

Water circulation inside the reactor vessel is by convection, upwards through the core and downwards between the core and thermal shield. The flow diagram of the system is shown in Fig. 9.

The water level in the reactor is held constant by a control system of the 3-element type, responsive to water level, water flow and steam flow, and adjusting the feedwater so that under steady-state conditions the feedwater flow is exactly balanced to the steam requirements.

Feedwater enters the reactor through a spray ring surrounding the core and, mixing with the downcoming reactor water in the annular space around the core, cools it slightly, thus assisting the normal convection flow. Circulation is such that some 130 lb of water is circulated through the core per lb of steam generated. The steam flow at full load is approximately 9,020 lb/h at 300 p.s.i. and saturation temperature (approx. 420°F). Steam first

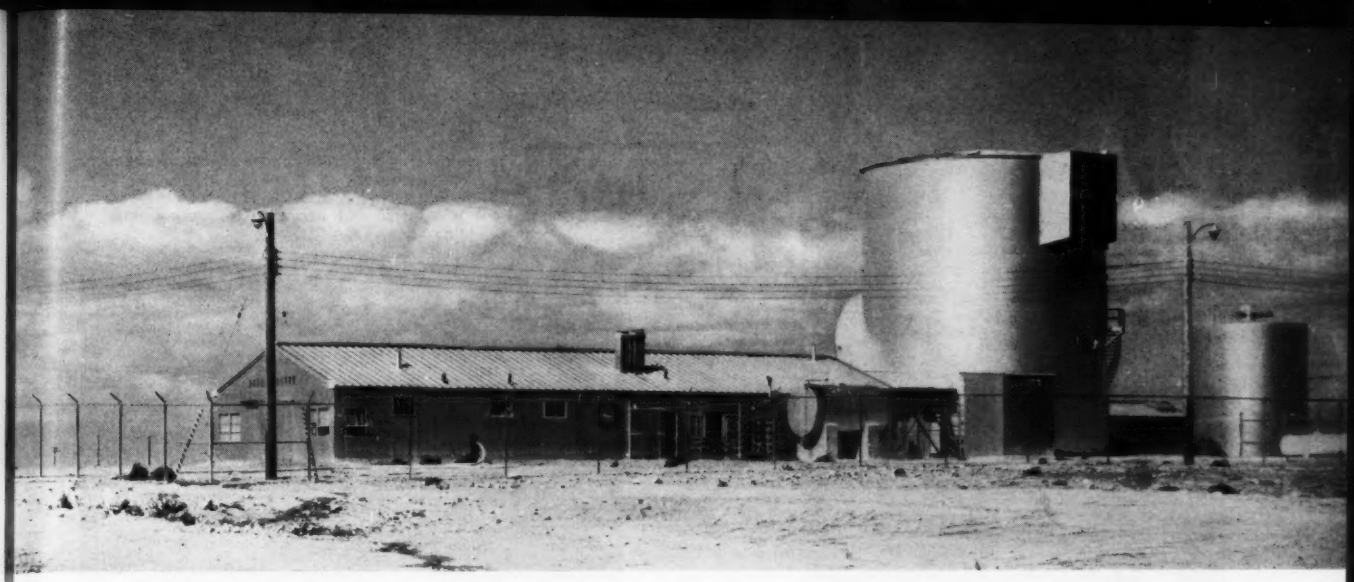


Fig. 8.—General view of the complete station.

passes through a separator, then about 85% is used in the turbine, which is of conventional design, and operates at 275 p.s.i. The remaining steam is used for space-heating purposes; in the prototype reactor, this is simulated by an air-cooled heat exchanger.

The turbine condenser is particularly interesting, in that it is air cooled of aluminium fin-tube construction, the air being circulated over the finned tubes by a 90-in., 75-h.p. fan at the rate of some 93,000 cu. ft/min. The vacuum obtained is approximately 25 in. (or, to adopt the U.S. terminology, corresponds to an absolute pressure of 4.85 in. Hg).

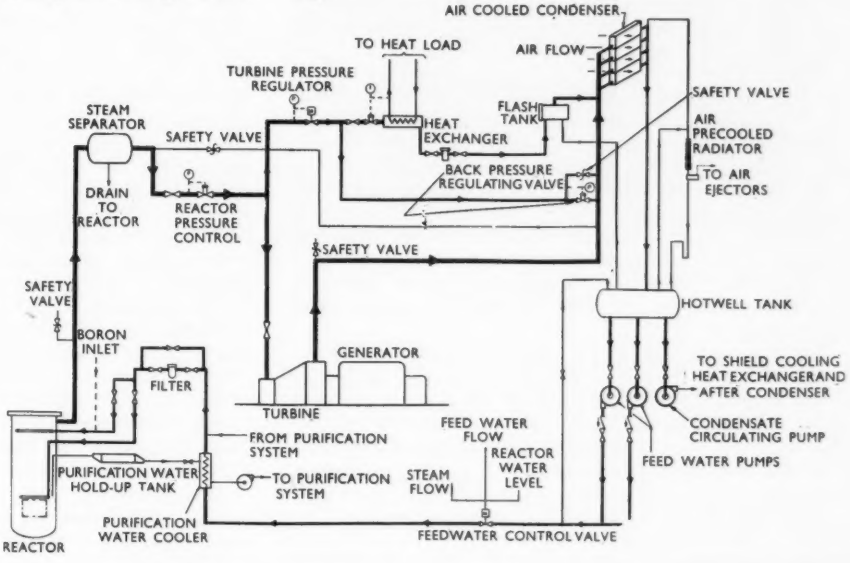


Fig. 9.—(Right) Simplified flow diagram.

Table 2. General Reactor Data

Heat output, total	3 MW
Average steam voids in heated channel	9%
Average steam voids in moderator	7%
Water recirculation ratio (lb water per lb steam)	130
Inlet temperature	175°F
Sub-cooling at channel inlet	1.8°F
Average boiling length of core	20 in.
Heat transfer area (40 elements)	475 ft²
Average heat flux at min. loading	21,500 B.t.u./ft², h
Fuel temperature at centre line (average)	450°F
Fuel temperature at plate surface (average)	440°F
Pressure vessel outside diameter	4 ft 6 in.
Pressure vessel height	14 ft 6 in.
Pressure vessel wall thickness base metal	½ in.
Pressure vessel wall thickness cladding	$\frac{3}{16}$ in.
Thermal shield thickness	½ in.
Height of water above core	4 ft 3 in.
Total weight of water	6,000 lb
Thermal stress in vessel due to γ ray (max.)	750 p.s.i.
Thermal stress in vessel due to γ ray in cover (max.)	600 p.s.i.
Design stress	14,000 p.s.i.
Design pressure	400 p.s.i.
Steam pressure	300 p.s.i.
Steam temperature	420°F
Steam flow (at 300 kW)	9,020 lb/h

Feedwater pumps are of conventional design. All returned feedwater is filtered to prevent corrosion products entering the reactor and being carried in irradiated form by the steam. Water in the reactor vessel is continually bled off through a purification system at the rate of 5 gal/min.

Enclosure and Shielding

The main housing for the ALPR is a welded steel cylindrical tank 38 ft 7 in. diameter, extending 50 ft above ground level. The bottom of the tank rests on concrete piers 2 ft above ground level, to give an air space and reduce thermal heat transfer into the ground. The tank serves as a weather shell; there is an independent structural framework inside for supporting the plant. Two floor levels are provided, the operating floor being 19 ft 4 in., and the fan floor 32 ft, above tank bottom. The reactor,

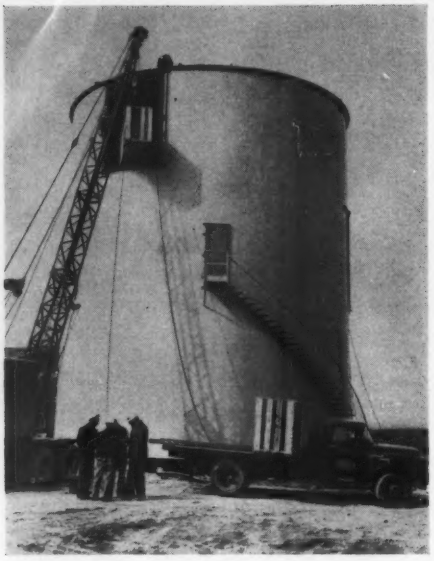
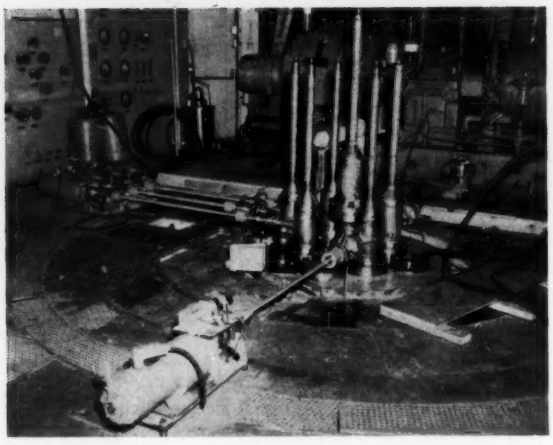


Fig. 10.—(Left) Erection almost complete: a section of the condenser being delivered.

Fig. 11.—(Below) General view of control rod drives on operating floor, shielding removed.



three fuel element storage wells, and other apparatus are located below operating floor level. An enclosed stairway, an open emergency stairway and a "cargo door" in the tank wall all lead to the operating floor. Access to the fan floor is through a hatch and air-lock.

The fan chamber contains the condenser and fan, ductwork, and a mixing chamber through which a proportion of the total air flow is recirculated by thermostatically controlled dampers, so that freezing of the water is prevented in conditions of very low ambient temperature.

The reactor vessel assembly is supported by its top flange resting on a supporting cylinder fabricated in two semi-cylindrical portions which, in addition, furnishes additional shielding, with a lead blanket 1¼ in. thick, having embedded cooling coils. The lead is contained in a ¼ in. jacket; at core level, additional shielding is provided by a steel band 1¼ in. thick.

Local gravel is used as the biological shielding, and the lower portion of the tank is filled with gravel to within 2 ft of the operating floor. In addition, boral plates are used beneath the reactor and, both above and below the reactor steel shot and boric oxide are mixed with gravel and sand. Top shielding on the operating floor is of concrete, cast in removable sections; a portion of the floor is covered with a removable shield of laminated masonite and steel.

Control and Safety

The control equipment is located in a separate building which also houses workshops and offices.

In the control room instruments and controls are segregated into process control and reactor control. The reactor control includes six channels of neutron instrumentation for the range from source level to full power. Fuel element failure detection is by scintillation counter, monitoring the activity of the exhaust gas from the air-ejector system.

Table 3. Estimated costs to June, 1958

Engineering Design and Inspection	$ 207,000
Site Improvement	$ 77,000
Construction and Installation*	$1,030,000
Reactor Components, Instrumentation Long Lead Equipment and Final Assembly	$ 496,000
Support Facility Equipment and Furnishings	$ 39,0 0
	$1,849,000*

* Includes site supporting facilities in addition to the power plant.

Process instrumentation contains, in addition to the normal automatic controls for turbine operation, three other control systems. Instability due to fluctuation in steam demand is avoided by pressure control, consisting of two parallel valves, by-passing steam direct to the condenser, so that the by-pass flow is proportional to pressure deviation from a set point. Water level control has already been described; the operator has the choice of the 3-element system or single-element, responding to water level alone. The air recirculation in the condenser system, previously mentioned, is regulated by damper motors controlled by 12 thermocouples across the inlet face of the condenser. Normal inlet temperature is set at 40°F.

Throughout efforts have been made to keep control simple and reliable, and to utilize standard components. The present reactor has, of course, a considerable amount of instrumentation for experimental measurements, which would not be necessary in a production unit.

Costs

The overall cost of the project is estimated at $1,986,000. Table 3 gives a breakdown of working estimates (less contingency allowances) to June, 1958.

LIST OF CONTRACTORS

PIONEER SERVICE AND ENGINEERING CO., 231 South La Salle Street, Chicago 4, Illinois.
Architect-engineer.

FEGLES CONSTRUCTION CO., INC., 711 Wesley Temple Building Minneapolis 3, Minnesota.
General contractor.

CHICAGO BRIDGE AND IRON CO., 332 South Michigan Ave., Chicago, Illinois.
Reactor building shell and structural steel.

WORTHINGTON CORP., Wellsville, N.Y.
Turbine-generator unit.

LASKER BOILER AND ENGINEERING CORP., 32nd and Wolcott Avenue, Chicago, Illinois.
Pressure vessel and support cylinder.

MODINE MANUFACTURING CO., Racine, Wisconsin.
Air-cooled condenser.

ILLINOIS WATER TREATMENT CO., Rockford, Illinois.
Reactor water purification system.

LEEDS AND NORTHRUP CO., 4901 Stenton Ave., Philadelphia 44, Pennsylvania.
Process and neutron instrumentation.

NELSON ELECTRIC CO., P.O. Box 5385, Tulsa, Oklahoma.
Metal enclosed low voltage switchgear.

BOGUE ELECTRIC MANUFACTURING CO., 52 Iowa Avenue, Patterson 3, New Jersey.
Emergency power supply.

INGERSOLL-RAND CO., 400 West Madison, Chicago, Illinois.
Feedwater pumps.

ALCO PRODUCTS, INC., Schenectady, New York.
Control rod drives.

RELAYS—and Reliability

The Case for the P.O. "3000"

By J. J. SMITH
(*Atomic Power Construction Ltd.*)

The inherent reliability of the P.O. type of relay is such that, in the author's opinion, duplication and even triplication of relays in reactor control circuits is often unnecessary. It is, however, hardly possible to exaggerate the importance of adequate protection from dust.

RELAYS perform an important function in nuclear reactor safety circuitry in co-ordinating signals from the various instruments to initiate a reactor shut-down should one indicate danger. Relays have been used in both experimental and industrial installations to perform similar functions but, because of their very simplicity, and tolerance of misuse, there has often been a tendency for relay circuits to be under-designed, particularly in systems where switching is not the most important feature.

Because of the critical reliability requirements, not only have reactor safety circuits been designed to ensure that the occurrence of relay faults will not endanger the safety of the reactor, but precautions are taken to cover every possibility of failure, however remote. These—perhaps exaggerated—precautions, combined with the somewhat casual use of the relay in the past, have given rise to unnecessary doubts as to its reliability as a component. There is no reason why the relay should not be employed with complete confidence, providing certain fundamental principles of application and protection are observed. For example, dust is perhaps one of the greatest hazards to the correct functioning of relay contacts and many types of enclosed relay have been developed during recent years which either have covers to minimize dust collection and mechanical damage to contact springs or are actually hermetically sealed.

No other relay provides such a comprehensive range of contact assemblies and facilities as the Post Office 3000 type, widely used for automatic telephone work by the G.P.O., and it is hardly putting its claim too high to suggest that it is the most reliable unit available, being built to a high standard of performance, yet designed so that it can be manufactured to reasonable tolerances at a cost which is not prohibitive.

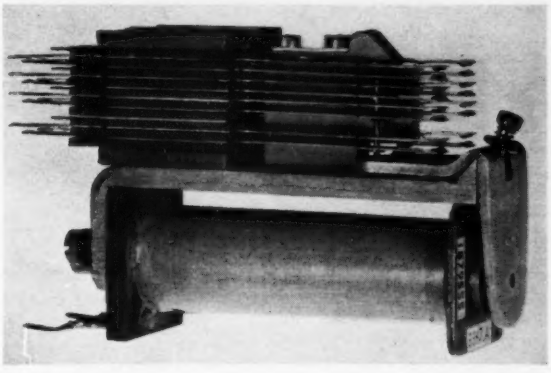
In order to obtain this uniform working without complication, standard values of safety factor, expressed in terms of spring-set load on the armature are included in design calculations. Typical values of current for a particular relay are given in Table 1, showing for each condition, a "test" and "circuit limit." The calculation of releasing and non-operating values is arranged to ensure that the contact pressure and the "opening" clearance are maintained at the "test" current level. The relay will, however, withstand much higher currents without operating.

TABLE 1
Design limits of P.O. 3000 relay

	Test	Circuit limit
Operating current	22 mA	46 mA
Holding current	14 mA	30.6 mA
Releasing current	5.5 mA	2.54 mA
Non-operating current	10 mA	7.4 mA

These values of "test" and "circuit" limit are based on many years' experience and research. They allow the manufacturers to offer a design to meet the hundreds of varying requirements with confidence, and permit the design of a circuit which will operate without any possibility of failure due to variations in piece part manufacture and adjustment. Circuits should only be designed outside these limits in consultation with the manufacturer.

Special features can be built into the relay; for example there is the impulsing relay which is required to repeat,



Standard G.P.O. type relay. (Courtesy Siemens Edison Swan Ltd.)

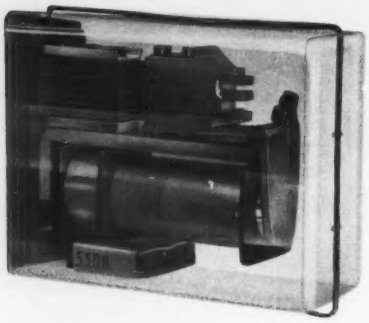
faithfully, impulses to another part of the circuit. Changes are also made to the characteristics of the core and magnetic circuit as well as to spring tension to meet special current requirements but, in all special cases, the manufacturer should be consulted.

Plug-in Construction

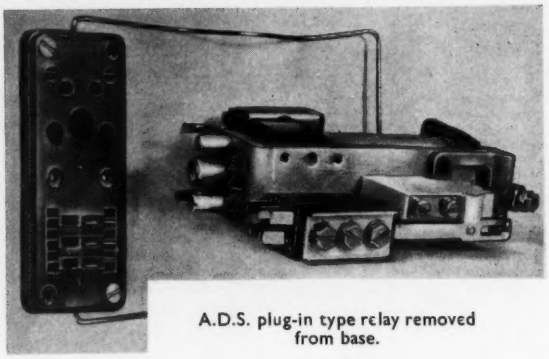
Relays which can be plugged in are an advantage where time is an important factor and the replacement of the relay can be effected by semi-skilled labour. It can also be considered an advantage, during the construction stage where the circuit can be completely wired without fitment of the relay, but plugs can become a source of trouble. Some years ago, the British Post Office introduced permanently wired relay circuits on what could be considered the most important and most complex circuits of a particular type of telephone exchange. The physical size and the number of connections in these circuits made handling difficult and the fault liability of so many plug points was felt to be excessive.

It should also be mentioned that, although the vast majority of telephone exchange equipment is removable, fault localizing is more easily carried out with the "relay set" in situ than it is on the test bench. On the other hand, however, in reactor safety circuits, the replacement of a faulty set with a serviceable one is considered a better approach than clearing the fault in situ and probably involving a longer reactor outage time. This method of

servicing has certain advantages as it can be assumed that if one contact has failed due to dust, others may also fail; the occurrence of one fault indicates that a complete overhaul is necessary.



Plug-in type P.O. relay with dust cover. (Courtesy A.D.S. Relays Ltd.)



A.D.S. plug-in type relay removed from base.

Protection from Dust

The use of the 3000 type relay in the nuclear field which demands 100% reliability, emphasizes the value of providing this relay with a transparent cover. Such a cover should not increase the overall dimensions to any large extent and should accommodate the maximum number of contacts. The transparent cover permits visual inspection, excludes dust and forms a valuable protection against mechanical damage. The cover should be removable to facilitate testing and readjustment if necessary, but with full vision transparency the purposeless removal of the cover, the very action of which is to draw dust, which has settled on its top, into the relay, is eliminated. One telephone system which employs completely covered equipment offers a virtually fault free system proving that protection from dust is vital in maintaining a high standard of performance. The provision of air conditioning is also an advantage, but precautions must still be taken against dust which is carried in clothes and, what is far worse, the minute particles of cloth fibre, which are falling constantly and form most efficient insulators.

Other Possible Faults

Since faults due to collection of dust and foreign matter should not occur if suitable protection is provided, possible failure should then be confined to open circuiting of the coil, caused by corrosion due to the ingress of moisture. With coils which are normally current carrying, sufficient heat should be generated to prevent this happening, but in the light of this possible fault, and the necessity of reducing outage time, it is considered advisable to carry replacement sets. Care must be taken to store these under operational conditions where they can be protected from dust and mechanical damage.

Contacts which have failed in circuits of good design can, in most cases, be traced directly to faulty adjustment, establishing conditions under which the relay could not be expected to function properly. Although adjustment is required to close tolerances, the routine is comparatively simple, using the special tools provided. Wider tolerances can be adopted when checking relays provided the " test limits " are not exceeded. The object of a wider tolerance on checking is to allow for subjective differences (human element) and for variations in measuring instruments. It also accommodates slight changes throughout the life of the relay.

Twin dome contacts are provided on 3000 type light duty relays and each dome being separately sprung reduces the probability of failure due to dust between the contacts, by a factor of 10. This figure has been derived by analysis of tests made under operational conditions. Perfect alignment of the twin dome contacts is essential in maintaining this factor. Light contact pressures will result in a poor contact. On the other hand, if they are too heavy the load on the armature could be increased to such an extent that on extreme current limits the " break " contacts may not open sufficiently to open the circuit. Light contacts can reduce the travel or " follow " on some springs and the self clearing action will be less effective.

Sparking

Sparking in many instances is unavoidable, but circuit design can often reduce this condition to a minimum when it is caused by highly inductive circuits. Relays can be designed having fewer turns on their operating coils thus reducing the inductive effect. Sparking may also be caused by faulty adjustments, giving rise to contact bounce. If this occurs when the inductive effect is at its peak, excessive sparking could cause the contact surface to become damaged and the " pitted " surface is now more prone to the collection of dust. This will increase sparking, aggravating the condition which is cumulative. The ultimate effect on the contacts will inevitably be that they will stick (weld) and the light spring tension will reduce considerably their separating power.

Relais et Sûreté de Fonctionnement

Lorsque il-y-a une panne dans les circuits de relais, la faute en est le plus souvent au circuit ou à une cause extérieure. Le présent article fait ressortir la sûreté de fonctionnement d'un type particulier de relais employé par les P.T.T. Britanniques et déclare que les pannes de relais sont d'habitude dues à une négligence dans l'exclusion des poussières, ou dans la conception des circuits hors des limites de fonctionnement du relais.

Relais und Zuverlässigkeit

Wenn Relais Stromkreise versagen, findet sich der Fehler öfter im Stromkreis selbst, als dass äussere Ursachen vorliegen. Der Aufsatz betont die Zuverlässigkeit einer besonderen Art von Relais, die von der britischen Postverwaltung verwendet werden, und weist darauf hin, dass Relais Versager gewöhnlich auf Nachlässigkeit im Schutz gegen Staub zurückzuführen sind, oder darauf, dass Stromkreise vorgezeichnet sind, die ausserhalb der Grenzen liegen, innerhalb derer das Relais arbeiten soll.

Relais y Seguridad de Funcionamiento

Cuando fallan los circuitos de relais, la falta casi siempre se debe al circuito o a alguna causa externa. Este artículo trata de la seguridad de un tipo especial de relai que se viene utilizando por el Servicio de Correos Británico e indica que las fallas de relais se deben generalmente al descuido en la exclusión de polvo o al diseño de circuitos que exceden los límites operativos del relai.

Sparking between relay contacts causes metal transference from one contact to the other (from negative to positive) and constant sparking tends to cause a " pip " to form on the positive contact and a cavity on the negative one. This " pip " offers a smaller contact area causing higher current density at the point of contact. The dissipation of heat is also considerably reduced, a further cause of contact welding. It is essential, therefore, that quenching circuits are provided. These usually take the form of a condenser in series with a resistor, the value of which is critical; selection of the correct value is usually best obtained by experiment. Other methods of quenching can be used and silicon carbide discs have proved very effective. If, however, there is any chance of breakdown of the quenching component likely to cause a low resistance path (shorting) it is important that the quench circuit is connected across the coil of the relay which must release to safety, rather than across the contact which would prevent the release of the relay. Silicon carbide discs may prove more suitable in this application and will possibly have no effect on the operating time of the relay. The release timing of the relay will be affected to some extent by both methods.

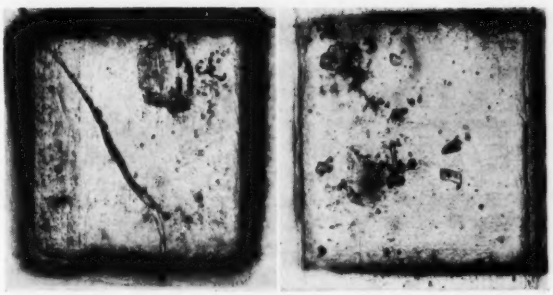
Care of Contacts

During installation and acceptance testing of equipment, it is important that there should be skilled supervision, as some of the greatest hazards to correct functioning of the relay arise from rough handling. During testing, relays should not be left open for long periods and if possible only the relay directly concerned with the test should be uncovered. It is far easier to prevent dust collecting on the relay springs and surrounding parts than it is to remove. Should, however, it be necessary to clean relay contacts, care must be exercised in selecting a cleaning material which will not leave small pieces of fibre between the contacts. Special burnishers are available to ensure that the contacts are clean and polished but on no account should files be used for this purpose as they will scratch the contact surface.

Routine testing of contacts (mechanically) as a general rule, is not recommended, but an electrical test should be made at frequent intervals, where relays are normally static. Relays in safety circuits will normally be energized and the frequent routine testing will tend to keep the contacts in good condition (the operation of the contacts having a self cleaning action). Provided sufficient spark quenching is built into the circuit, routine testing can be of great value not only in showing up any weakness, but in maintaining healthy circuits and a long fault-free life. Contacts which are closed and are not carrying current tend to build up an insulating film, causing them to become open circuit.

This is more common with silver contacts where a sulphide film is likely to occur, especially in industrial areas or where they are in close proximity with rubber. It is also possible for contacts to become coated with a grease film, particularly where the wrong cleaning material is used.

Experiments have been made using gold alloy contacts with a test voltage of 40 V where it was noted that the normal closure of a contact displaced the grease film and a good contact surface was made. If the contact were not carrying current, in a matter of hours—and even as short a period as 10 minutes—the grease film would creep back, and eventually break the circuit. From tests made on normal equipment, it was found that contacts not carrying current gave 10 times the trouble of current-carrying



Photomicrographs of plastic replicas showing palladium relay contacts after failure due to (left) a large cotton fibre, smaller fibre fragments and erosion dust ; (right) phenol fibres.

The plastic replica technique is due to H. W. Hermance and T. F. Egan of the Bell Telephone Laboratories, to whom we are indebted for permission to publish these illustrations.

contacts. It is, however, recommended that platinum should always be used for trip line contacts, owing to its complete immunity to the formation of oxide films and tarnishing, especially where contacts may remain idle for long periods.

Relays of the 3000 type having fixed residual studs and reasonable armature loads cannot be associated with " fail to release faults " once the operating coil has been disconnected. This type of fault is not possible with modern relay design and no precautions need be taken to cover this.

Trip Circuits

To avoid using unnecessarily long series-connected circuits, contacts which would normally be connected direct in the trip line, can be arranged in a number of smaller circuits by using secondary relays; the correct functioning of these additional components being proved by a system of regular testing. This may not reduce the number of terminations required to connect the remote contacts to the safety equipment, but no line terminations need now enter the actual trip line, and no shorting fault on the line can by-pass any part of the trip line.

Conclusions

Owing to the static state of relays in safety circuits, wear is negligible, and with routine testing, even at a frequency of once every hour, the life of the relay would run into some hundreds of years. The fact that a relay has moving parts can therefore be disregarded, and it should be considered as a simple but versatile switching element, capable of switching powers of up to 50 W in a number of simultaneous applications using standard contacts and considerably higher powers with heavy-duty contacts.

Although no faults need occur, a general survey has been made of common fault causes which arise from bad maintenance and poor design. The circuit designer plays a most important part in ensuring fault-free service from relays; it is his responsibility to produce a simple system which does not depend upon marginal conditions.

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Expansion Joints

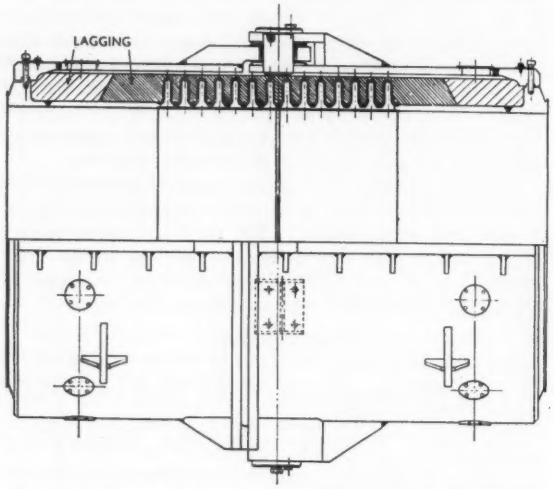
A review of current progress in the design, development and manufacture of large diameter thermal compensators for main gas coolant circuits. Brief details of expansion joints for steam services, and support assemblies for CO_2 circuits.

5 ft bore flexible connection by Teddington Aircraft Controls.

THE manufacture of large-diameter bellows units to compensate for thermal expansion has been rather neglected by British industry. Indeed, it was not until the U.K. Atomic Energy Authority embarked on the construction of Calder Hall that industry became aware of the manufacturing problems involved. Even now, after several years of development work, there are few British concerns who can offer thermal compensators that will completely satisfy the temperature/pressure conditions encountered in large-diameter gas-coolant circuits.

The present position is that of the four commercial nuclear power generating stations in course of construction, three are making use of bellows convolutions fabricated by a German concern, Industrie-Werke Karlsruhe. At the fourth station, Bradwell, bellows will be supplied by C. A. Parsons, a member company of N.P.P.C. Parsons have already acquired a great deal of manufacturing experience as the company was responsible for all the main expansion joints at both Calder Hall and Chapelcross.

So far as large-diameter bellows are concerned there are several main methods of manufacture. First, the material can be of the same thickness as the duct itself. The sheet is pressed out to a channel section with a depth of from 4 to 6 in. Normally one corrugation is formed at a time and the convolutions are subsequently assembled by circumferential welding.



Typical 4-ft 6-in.-diameter expansion joint for main gas coolant circuit at Calder Hall (C. A. Parsons).

Secondly, a comparatively thin bellows (from 20 to 60 thou. thick) can be cold formed in one piece, the complete unit being fabricated by a single transverse weld. For high pressure, high temperature applications a bellows formed in this way requires considerable reinforcement.

Thirdly, it is possible to form the convolution hot from material $\frac{1}{8}$ in. thick by a special hot spinning process. In the past few years this method of manufacture has gained wide acceptance for high-pressure applications.

As Calder Hall was responsible for the first British large-diameter expansion joints capable of withstanding high-temperature and high-pressure conditions a description of them would not be out of place at this point.

Although C. A. Parsons were responsible for the design of the Calder bellows, the actual fabrication was carried out in collaboration with a number of associate companies such as Head Wrightson, Clarke Chapman and Robert Jenkins. The design has previously been described by A. T. Bowden and G. H. Martin in their joint paper "Design of Important Plant Items" (Calder Symposium, B.N.E.C., October, 1956).

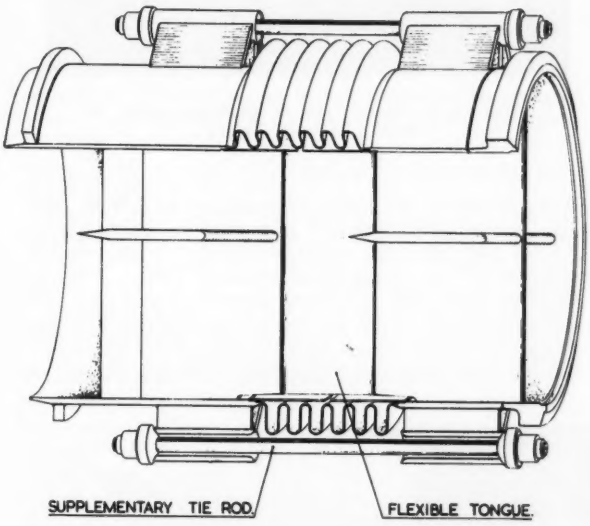
The shape of the corrugations was influenced by previous experience where a working stress of 12 tons/sq. in. was used for deep drawing quality steel with an ultimate stress of 20 tons/sq. in. Accordingly, for the Calder units, the allowable maximum stress was raised to 14 tons/sq. in. with an ultimate tensile stress of 26 to 30 tons/sq. in. To prevent the bellows becoming unstable the number of corrugations in any one unit was limited to 14. An optimum height-to-thickness ratio was established by calculation. The problem of carrying the concentrated end load of approximately 150 tons for the design pressure of 125 p.s.i.g. from the pins to the flanges in such a way as to prevent distorting stress led to the construction of a series of models which were tested by the research department of Lloyd's Register of Shipping. In the final design the bellows were contained in an axially split and bolted casing spigotted to the flanges. The casings were circumferentially stiffened at the joints to avoid undue deflection of the hinge pin. The pins are of nitrided steel in lead-bronze bushes.

Because there were little data on the behaviour of large-diameter flanged joints which would meet the proposed operating conditions, a forged taper tail type with metal-to-

metal mating faces finely machined was adopted. The total depth of the face is 2½ in. but this is relieved to a maximum of 0.003 in. over approximately half the depth. The sealing lip, approximately ½ in. long and feathered to 1 in., allows a fine sealing weld.

The Calder joints were subjected to full-scale tests to check the stresses involved. Lloyd's Register of Shipping collaborated in the series of experiments and a number of useful results were obtained. Using strain gauges, the stresses set up in flanges and bolts during the tightening up process were recorded against varying loading applied by torque spanner. From an examination of the clearance measurements it was seen that at 400 lb, ft torque the inner edge of the joint had begun to open up at all points. This indicated that heeling about the outer-face circumference had taken place. The figure of 400 lb, ft was subsequently used for erection on site.

To examine the effectiveness of the bolted and seal-welded joints under operating conditions, flanges were welded to dished ends and the assemblies bolted and seal welded in accordance with specified conditions. Two assemblies were made, identical in all respects except that the seal welds were made with the flanges fixed in one case



Restrained bellows joint developed by C. A. Parsons for the main gas ducts at Bradwell.

vertical and in the other horizontal to simulate site operations.

The assemblies were pressurized to 125 p.s.i.g. with CO_2 and internal electric heaters were used to bring them up to 350°C. The pressure was then suddenly released and cold CO_2 forced in to give a rapid cooling effect. Each system was again pressurized, brought up to temperature and tested for leakage so that the cycle could be repeated. Throughout the series of tests there was no leakage or sign of cracking of the weld. The expansion joints at Calder have proved entirely satisfactory in service.

For the Bradwell station, C. A. Parsons have decided to uprate the bellows so that each will handle axial loads of up to 200 tons. Because loads of this magnitude would be difficult to sustain without large frictional forces in external hinges of conventional design, the load is carried through an internal tongue. The Bradwell bellows are 5 ft in diameter and the CO_2 pressure at the circulator inlet is 139.4 p.s.i.a. A typical Bradwell bellows is shown in the accompanying drawing.

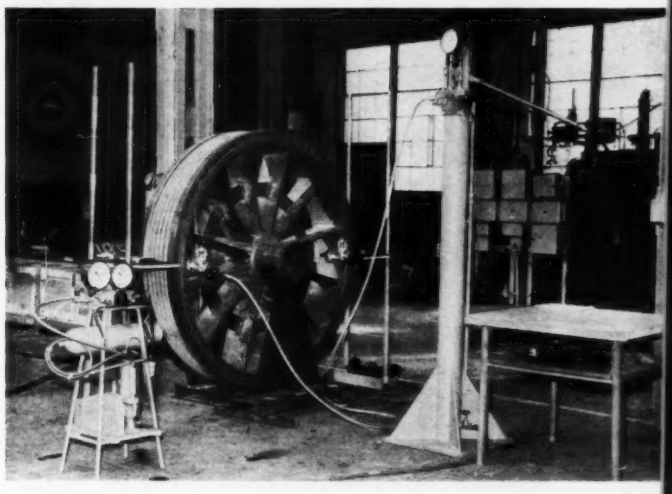
Engineering Appliances

With a research and development programme extending over many years, the German company I.W.K., of Karlsruhe, has made considerable progress in the development of large-diameter bellows. The I.W.K. convolution is formed hot from ¼-in.-thick material by a special spinning process. This method produces a compact and re-entrant type of convolution which is an excellent compromise between the deep-drawn convolution and the thin hydraulically formed kind. Pressure of several hundred p.s.i. can be taken on bellows of 5 or 6 ft diameter with sufficient elasticity to give adequate performance and life.

I.W.K. bellows are marketed in the U.K. by Engineering Appliances. Following prototype tests on 5-ft-diameter bellows nominally at 165 p.s.i. and 750°F at the I.W.K. works, Engineering Appliances have received orders for about 250 compensators of that size covering all the main ducting requirements of the Berkeley (A.E.I.-John Thompson) and Hunterston (G.E.C.-Simon-Carves) stations.

More recently the company has carried out tests at 230 p.s.i., 770°F on 5-ft 6-in.-diameter bellows. After these tests, which were entirely successful, an order was placed by English Electric/Babcock and Wilcox/Taylor Woodrow for bellows to be supplied for the main ducting at Hinkley Point. Details of these tests were recently released. The bellows used were of standard chrome-molybdenum steel (about 1% Cr, ½% Mo, etc.) heat treated to give highest tensile properties. The bellows thickness was ⅛ in. with a bellows height of about 2½ in. and pitch about 1½ in. which is their standard. Eight convolutions were used for the life test, five convolutions for the bursting test.

The bellows was mounted within a flange and anchor assembly to allow angular movement but to withstand the bore load imposed by the internal pressure attempting to open out the bellows. These forces were extremely large; at test pressure well over 716 tons had to be restrained. The assembly was, of course, exceptionally heavy, the angular movement being taken on plain high-grade alloy pins outside the bellows, leaving a perfectly clear internal bore.



Set-up for conducting bursting test on 5-ft 6-in.-diameter bellows at the I.W.K. works, Karlsruhe, Germany. The bellows are shown in the deflected position on the spider mounting.

The pin surface was specially treated. Hemispheres were welded on the end of the unit, the overall length of the bellows itself being only about 6 ft 6 in. The whole unit was placed within an insulated container, heated internally by electric elements and filled with CO_2. Movement was imposed by a motor gearbox and crank assembly and strain gauge moment and temperature measurements were made.

After various preliminary measurements, strain gauging, etc., the officially specified life of 2,500 movements (half hot, half cold) was successfully achieved, with temperature and pressure drops at specified intervals to simulate working conditions under a total angle of 3°. As there appeared to be no sign of distortion or failure, the test was carried through to 12,000 double movements, continuing with temperature and pressure drops to atmospheric. After this the angle was increased to a total of 5°. The bellows continued operating for a further 2,520 movements when it failed by a gradual crack exactly as expected, non-destructively.

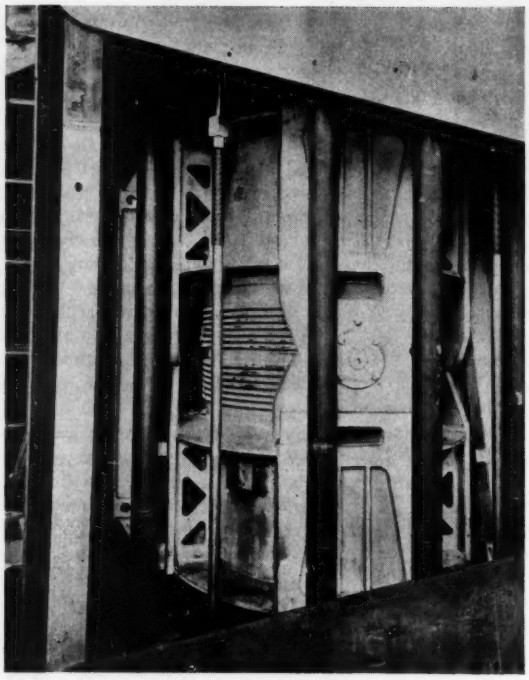
The same pins were used throughout the test and were still in reasonable condition after the 14,500 movements. During the test, conducted at a pressure of about 460 p.s.i., measurements and strain gauge results showed very small distortions and no permanent set.

The bursting test was effected by containing the bellows within a spider assembly with the bellows on the deflected position. The assembly prevented the bellows opening out bodily and this was a genuine test on the convolution itself.

The bellows was evacuated, filled with water and then subjected to increasing pressure steps to note the onset of deformation and failure. Final failure was caused after very considerable distortion, at over 1,100 p.s.i., about five times the nominal working pressure. Heat was not applied to the bellows during this test.

British Thomson-Houston

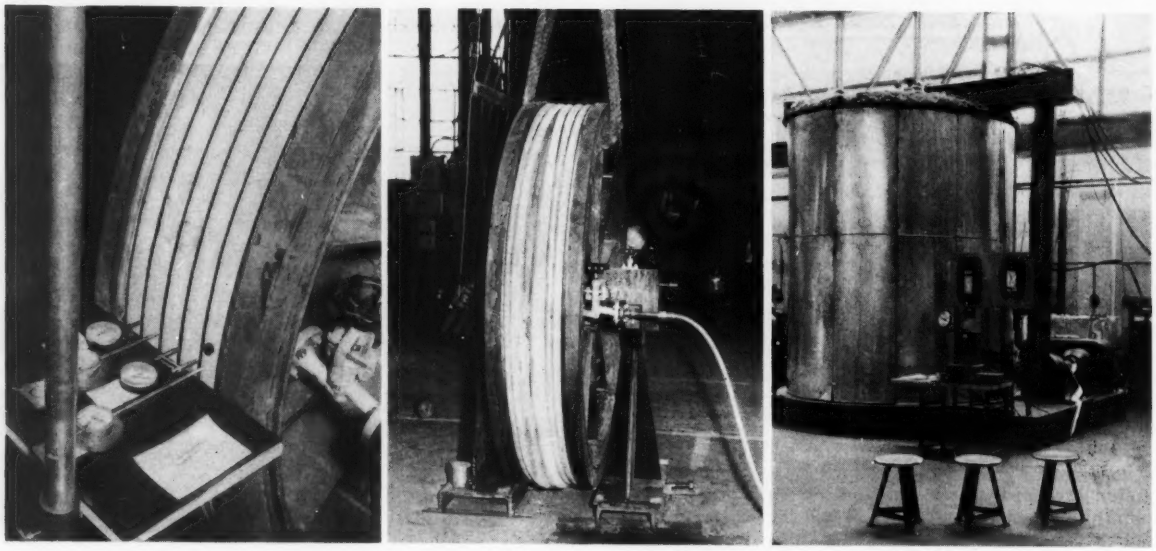
At the Rugby works of British Thomson-Houston the development of bellows units has been accelerated since the A.E.I.-John Thompson Group (of which BTH is a member) were awarded a contract by C.E.G.B. for the construction of Berkeley nuclear power station.



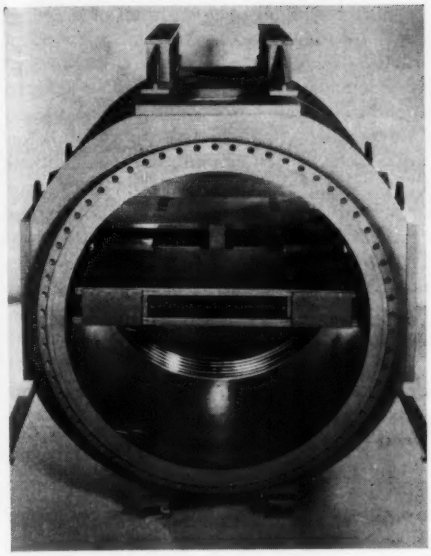
Test rig for bellows unit at the Rugby works of British Thomson-Houston.

As previously mentioned, the convolutions for the Berkeley bellows are being manufactured by I.W.K. BTH are, however, designing their own complete bellows units.

Until now the usual constraint for a bellows unit has consisted of two hinges, one on each side. For the Berkeley units, with a working pressure of 250 p.s.i. and a duct diameter of 60 in., the end load which the constraints have to handle is approximately 350 tons. It was thought that hinge pin constraints would not be able to



Testing 5-ft 6-in.-diameter bellows at the I.W.K. works. (Left) Measurement of deflection at 1,100 p.s.i. (Centre) Deformation of bellows at high pressure. (Right) Accelerated life test rig.



Model of the special bellows unit developed by BTH for the main Berkeley gas circuits.

cater for such high loads, particularly as the hinge for the bellows in service would be at temperature and would probably not move for months at a time. Such conditions would be ideal for squeezing out any lubricant that may remain on the pin and also ideal for causing galling and seizure of the bearing surface.

If, under such conditions, galling or seizure occurred the resulting excessive torque to cause deflection of the bellows would probably dangerously overstress the pressure vessel at the weakest point—the duct branches. A disturbing feature of this is that galling of the pin surfaces would be unknown to the station operating staff.

The large gas pressure-loading is, in the BTH design of bellows, taken by two tie bars anchored at each end of the duct and inside the bellows unit. Deflection of the bellows causes flexure of the tie bars which are suitably shaped so that the bending does not incur excessive stresses.

The use of tie bars themselves, although a satisfactory solution of the gas loading problem, was not thought to completely solve all the problems associated with their use. For example, any dead weight, thermal, wind, or erection loads at one side of the bellows, not completely balanced out by hangers or any other suitable means, would have to be transmitted across the convolutions by either the convolutions themselves or the tie bars. By the very nature of the design of the tie bars these would not transmit very much of this loading and hence the convolutions themselves would have to carry the major part of the loading. This means that the weakest part of the bellows unit would be carrying additional " shear " loads for which they were not intended and because of this an early failure of the convolutions at site could easily occur—a failure due to forces which would not normally be applied during testing in a rig.

To transmit any such vertical out-of-balance forces that might be encountered at site, the Berkeley bellows units are made with brackets and hinge pins—the hinges being so designed that they do not take any axial (gas pressure) loads. In addition there are interlocking key brackets at each side of the bellows and at right angles to the hinges to transmit any side loads from one flange of the bellows to the other, so that the convolutions themselves are clear of this type of extraneous loading. Furthermore, both the key brackets and hinges take care of any extraneous torsional loading that might be applied to the unit.

This type of construction, has the following advantages:— (1) A definite and constant torque to deflect the unit irrespective of time and type of usage. The units are designed for a 20-year life. (2) A low value of torque resistance. (3) A method of preventing the weak element of the bellows unit (normally the convolutions) taking external loads forced upon it due to erection, distortion (thermal and permanent), wind, and settlement, of pressure vessels or foundations. (4) Minimum of distortion of the end convolutions and bellows flanges due to the internal constraints (compared to external constraints whether hinges or tie bars) reducing the moments on the bellows ends, which in turn reduces the possibility of convolutions failure and also flange leakage. (5) The hinges are sufficiently strong to act as a safety device should the internal restraints fail.

The prototype 5-ft-diameter bellows shown in the accompanying photograph has been tested under full pressure for Berkeley conditions and satisfactorily concluded a test of 21,000 cycles of maximum deflection at full gas pressure and temperature and a further 20,000 cycles at twice full pressure before failure of a convolution occurred due to corrosion fatigue.

To simulate conditions in service a prototype bellows should be subjected not only to deflection but also (at the same time) to cycles of pressure and temperature. If closer simulation is required it should also be subjected to conditions of corrosion and stress relaxation due to creep. Tests on prototype bellows have not, therefore, up to now simulated all conditions that occur in service.

Teddington Aircraft Controls

Teddington bellows are mostly 18/8 stainless steel, but special units are made in Monel, Inconel, the Nimonic series of alloys, Nilo K, titanium and other materials. Units range from 1-in. diameter to 10-ft diameter, and rectangular

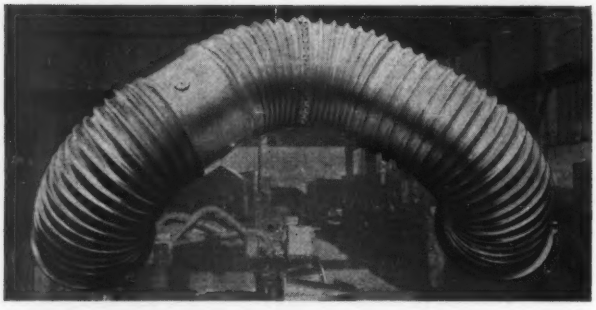
Butt-welded double-ended S.S. bellows assembly with welded-on flanges by Teddington Aircraft Controls.

expansion joints and " U " span assemblies can be as large as required. The condition of the metal, whether cold, annealed, or specially heat treated, has a great bearing on the life. Normally, Teddington bellows are in the cold

worked condition, but they can be heat treated or annealed where this is desirable.

At the Teddington laboratories bellows are tested to destruction on a machine which continuously repeats a controlled set of movements, with or without internal pressure applied to the bellows, so as to determine the fatigue life. Hydraulic tests determine the deformation and bursting pressures. Resonance search tests are made on vibration equipment. Metallurgical and microscopic analyses are made before and after the metal is worked.

Some bellows units are formed from seamless drawn tube, while the larger stainless-steel bellows are made from tube which is preformed from cold rolled sheet of accurate gauge, and joined with a longitudinal self-butt-weld. Various methods are used to make the convolutions, including hydraulic forming and several types of rolling. Units can be supplied in a pre-stressed condition, the set length being maintained by sizing bars tack-welded across the flanges.



Aiton corrugated cross-over pipe, of 30-in. diameter for installation between the H.P. and L.P. stages of a turbine.

Aiton & Co.

Although Aiton and Co. have many years experience of the manufacture of thermal compensators, the company does not, at the present time, make fittings for large bore gas coolant circuits. The company does, however, make support assemblies suitable for CO_2 circuits.

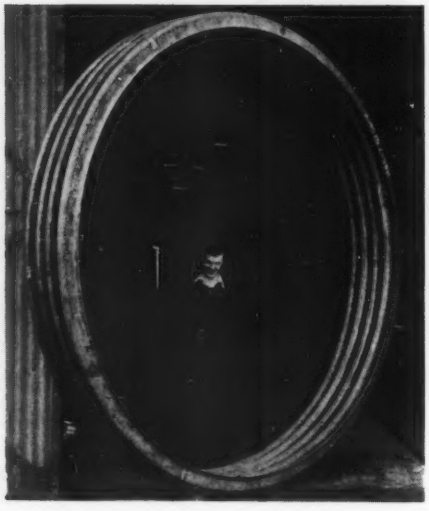
Aiton expansion joints are manufactured in ferritic or austenitic steels according to the working conditions and/or the corrosive action of the conveyed fluid or gas. The fittings can be supplied with flanged connections or prepared for butt-welding. In many cases, Aitons, as specialist pipework contractors, include their joints as an integral part of the piping scheme. In this connection it is worth noting that the company were responsible for the station pipework at Calder Hall. The standard range of Aiton joints covers units of up to 84 in. i.d., the convolutions being formed by pressing each individually. Groups of convolutions are subsequently welded circumferentially, the number varying according to the amount of expansion to be catered for. Aiton manufacture as well, a range of joints where the convolutions are formed by deep pressing: it is also possible to produce flat-sided convolutions by means of a further circumferential weld on the periphery of the convolution.

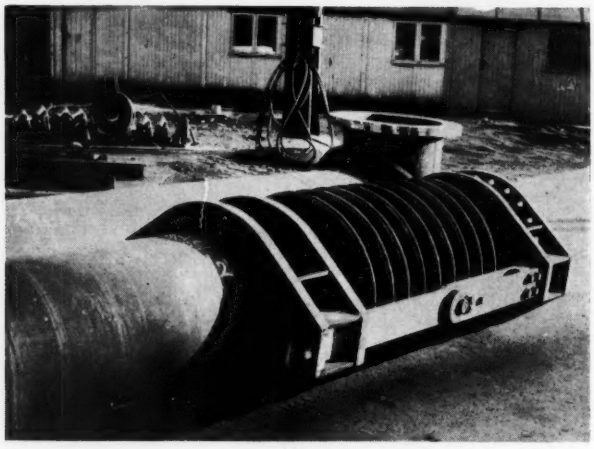
For small bore applications (from 6 in. to 14 in.) Aitons offer a pressed corrugated expansion joint manufactured from Firth Vickers S.S. plate. Under test a 10-in. bore joint with seven corrugations has been subjected to more than 50,000 deflection cycles at a pressure of 150 p.s.i.

For high-pressure high-temperature steam services Aitons offer a wide range of pipes, specially formed to cater for expansion with plain, creased or corrugated loops according to the application required. An accompanying photograph shows a 30-in. bore corrugated cross-over pipe for installation between the H.P. and L.P. stages of a turbine.

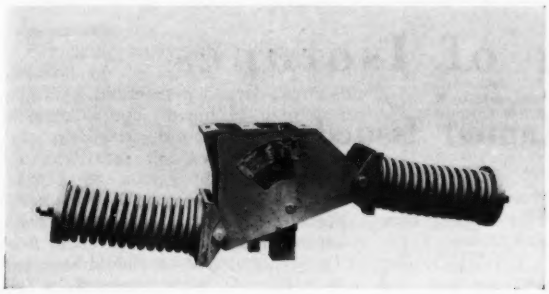
Power Flexible Tubing

Expansion joints made by the Power Flexible Tubing Co. take the form of corrugated bellows made from laminated S.S. tube. The corrugations are individually formed without thinning or weakening the material. After manufacture they are stress-relieved. Power Flexible's normal range of joints in sizes from $\frac{1}{2}$-in. bore to 24-in. bore is available for pressures of up to 100 p.s.i. (standard) or 200 p.s.i. (heavy duty). For higher pressures from 200 to 400 p.s.i. extra heavy duty joints can be supplied from 3-in. to 10-in. bore. All these joints are suitable for working temperatures of up to 300°C; special joints can, however, be produced for temperatures of up to 600°C. Although these units are not suitable for use in main CO_2 circuits they are widely used for sealing small bore valves and so on. The bellows themselves are protected by inner and outer telescopic sleeves.





Two examples of Aiton bellows. The convolutions of the large diameter unit on the left comprise welded sections. The fabricated bellows above is intended for heavy duty service.



The type W Genspring constant support hanger by Vokes Genspring Ltd. will handle loads of up to 30,000 lb.

Vokes Genspring

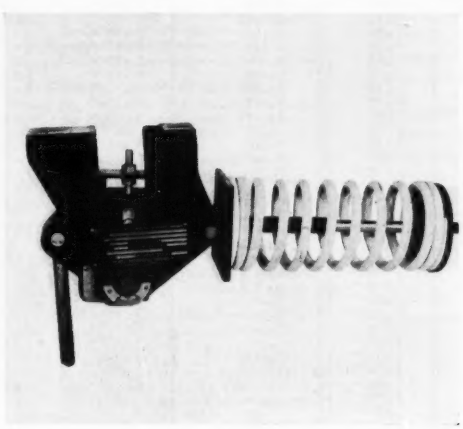
For the support of a piping installation where there will be vertical expansion due to thermal change, spring supports are a fairly obvious answer. The use of simple supports incorporating helical springs, however, will afford only variable load supporting capacity at the differing thermal conditions, as the expansion will alter the compressed height of the spring. To overcome this handicap, constant support hangers have been developed to reduce the effects of inadequate or excess support.

The Genspring constant support has been used in increasing quantities since 1930 for the support of high temperature piping. It has three main components. A main frame assembly can be secured direct to overhead structural steelwork, or be suspended from it by hanger rods. The main frame houses a lever unit free to pivot within the frame over 50° or 60° in different models and stops are fitted to the frame structure at the extreme travel positions. To one end of the lever is attached a spring assembly and to the other end of the lever sling rods can be attached down to pipe or duct brackets. The geometric design is such that the moment of the compressed loading on the spring assembly about the main pivot is always approximately equal to the moment of supported load.

For many years the type H.12 Genspring met the requirements of power stations, petroleum refineries and chemical processing. This support had a maximum load of 7,300 lb and maximum vertical travel of 4 in. In 1953 it was considered advisable to design for increased thermal movement and the type W Genspring was planned. The travel range was extended to 12 in. and approximately 4 tons load could be supported: at a reduced vertical travel of 3.381 in. a maximum load of 30,000 lb could be carried. This range was therefore suitable for the heavy concentrated loads in the Calder Hall CO_2 circuit. Initial orders were placed in 1954 for the supply of type H.12 and W supports for Calder A. These units have subsequently been supplied to Calder B and Chapelcross. Vokes Genspring are currently making hangers for the nuclear power stations at Berkeley, Bradwell, and Hunterston.

On completion of manufacture each support is adjusted to the mid-load setting and load reactions recorded over the full vertical travel in both directions, and from these figures the mid adjustment or rated capacity is established. The required alteration to load adjustment is then calculated which will meet the customer's service load, and a further test carried out to verify this. The degree of constant efficiency has been steadily increasing since 1954 and a satisfactory accelerated corrosion test was carried out on the W support by an independent organization, the Sondes Research Institute of Dorking.

During 1958 Vokes Genspring have been developing a new M range of constant supports which, while closely following the W design, offers increased efficiency at less cost. Models M.1 to 4 are now coming into production covering a load range of 350 to 22,000 lb over vertical movements up to 12 in. Larger capacity supports of up to 90,000 lb capacity are being designed, 28 of the larger model being required for Babcock and Wilcox at Hinkley Point. Additionally the M range is being extended to include floor-mounted-type supports which should be suitable for sections of ducting running at low level. The first M supports to be employed on nuclear power plant are of the M.2 class and supplied to the U.K.A.E.A. for the support of CO_2 circuit safety valve filters at Calder and Chapelcross.



Increased efficiency at lower cost is offered by the new Vokes M constant support hangers.

EXPANSION JOINT MANUFACTURERS

Accles and Pollock, Ltd., Oldbury, Birmingham. (Small dia bellows in austenitic stainless steel.)

Aiton and Co., Ltd., Derby. (Bellows and corrugated pipes for steam services; CO_2 support assemblies.)

Avica Equipment, Ltd., Mark Road, Hemel Hempstead, Herts.

British Appliances Mfg. Co., Ltd., Longclose Works, 52 Dolly Lane, Leeds 9. (Expansion pieces for secondary ducting.)

British Thomson-Houston Co., Ltd., Rugby, Warwicks. (Design and development of bellows units for CO_2 main circuit at Berkeley.)

Burnley Aircraft Products, Ltd., Welded Fabrications Div., Fulledge Works, Holmes Street, Burnley, Lancs. (Bellows of up to 2 ft. 6 in. dia in S.S. and M.S. to customers' requirements.)

Clarke, Chapman and Co., Ltd., Victoria Works, Gateshead, Co. Durham. (Sub-contractors to C. A. Parsons.)

John Dore and Co., Ltd., 60-70 Bromley High Street, Bow, London, E.3.

Drayton Regulator and Instrument Co., Ltd., Horton Road, West Drayton, Middx. (Hydroflex seamless bellows from 5/16 in. to 5 in. o.d. in 80/20 brass, phosphor bronze, Monel and S.S.)

Engineering Appliances, Ltd., 106 Victoria Street, London, S.W.1. (U.K. agents for bellows made by I.W.K., Karlsruhe, Germany.)

Robert Jenkins and Co., Ltd., Wortley Road, Rotherham, Yorks. (Sub-contractors to C. A. Parsons.)

W. G. Jenkinson, Ltd., 156-160 Arundel Street, Sheffield, 1.

Joseph Lucas, Ltd., Great King Street, Birmingham, 19.

Munro and Miller, Ltd., Moorepark Works, Tube Works, Ibrox, Glasgow, S.W.1.

Palatine Tool and Engineering Co. (Surbiton), Ltd., 64-76 Brighton Road, Surbiton, Surrey. (Hi-Presflex bellows, ½ in. to 8 in. bore in S.S., Monel or nickel for sealing valves and so on.)

Power Flexible Tubing Co., Ltd., Derby Works, Vale Road, London, N.4. (Bellows up to 2 ft. dia in stainless steel.)

J. Sankey and Sons, Ltd., Albert Street Works, Bilston, Staffs.

Teddington Aircraft Controls, Ltd., Industrial Bellows Div., Ammanford, Carm. (Large dia bellows for main CO_2 ducting.)

John Thompson (Wolverhampton), Ltd., Ettingshall, Wolverhampton, Staffs. (Manufacture of bellows units for Berkeley.)

T.I. Nuclear Engineering, Ltd., The Adelphi, London, W.C.2.

Vokes Genspring, Ltd., Henley Park, Guildford, Surrey.

Wilson Pipe Fittings, Engineering Division, P.O. Box 10, Irvine, Ayrshire.

Safe Handling of Isotopes

IAEA Draft Manual Issued

To meet the need for guidance in safe handling of radioisotopes, the International Atomic Energy Agency have prepared a draft manual. It is intended to act as a guide until set rules are established and agreed upon. Embracing the dangers and general precautions in the handling of radioactive isotopes, the manual also includes tables of the various isotopes and the maximum permissible concentrations. The original draft was prepared by the Secretariat of the IAEA and a panel of experts, spread throughout the world, was invited to prepare the final draft. A technical and medical addendum, to be issued separately, will also be published within the next 10 months.

It is intended that the information as tabulated in the draft, and of which extracts appear below, should be of more use to the small laboratory and manufacturer intending to handle radioactive material rather than the large-scale processor or the industrial user of radioactive isotopes.

Organization

Responsibilities and duties of personnel should be clearly set out to ensure safety, as workers cannot be expected to keep in mind all health and safety requirements whilst preoccupied with difficult operations. Authorities in charge should enforce rules and regulations and provide all necessary operating instructions and suitable equipment. Only medically suitable persons and staff with adequate medical training should be allowed to handle radioactive material and all persons liable to exposure to radiation should be instructed about the health hazards. It is highly desirable to appoint a radiological health and safety officer, who should have overall responsibility for the safety of installation and workers alike.

Medical Supervision

Certain medical requirements are specific to radiation work and emphasis should be placed on these as well as on normal industrial medical practice. Strict medical examination before employment is desirable as well as regular examination during employment. A casualty service capable of dealing with radiation dangers should be available as well. Young persons should not be occupationally exposed to radiation, and a minimum age of 18 should be fixed.

Determination of Radiation Exposure

This should include internal and external personal monitoring by instruments, and analysis of body wastes. For external monitoring the use of film dosimeters which permit measurement of the accumulated whole-body radiation dose over a period, is recommended.

Area monitoring by instruments and calculation should be carried out, and general monitoring should include radiation from external sources, contamination on surfaces of rooms and equipment, contamination of air and water, and of skin and clothing. This latter should be obligatory when persons are working with unsealed sources and nobody should leave the working place without being checked for contamination.

Records should be kept of each person exposed to ionizing radiations and should include: (a) Nature of work involving radiation and types of radiation; (b) extent to which individual has been exposed and, in particular, the accumulated dose of radiation received, which should be regularly computed; (c) Permanent records should also be kept of monitoring results.

Special use of Sealed Sources

High-intensity ionizing radiations should be used only with properly sealed areas which provide adequate protection for persons in adjacent rooms or floors. Teletherapy apparatus should be installed in a separate room protected by interlocks, and monitored.

Thickness gauges, static eliminators and similar devices using sealed sources should be constructed, installed and shielded so that radiation levels for all persons, including those installing them or working near them, do not exceed the normal permitted dosage for the general public, so as to render personnel monitoring or special medical examinations unnecessary.

In cases of breakage the "radiological health and safety" officer or other designated person is to be notified at once. This again stresses the importance of appointing such a person where radioactive material is involved.

Industrial Gamma Radiography

The controlled area should be clearly marked and made inaccessible to unauthorized personnel and audible and visual

TABLE 1

Maximum permissible concentrations in air and water for continuous exposures

Isotope	Maximum permissible concentration μc/cm³		Isotope	Maximum permissible concentration μc/cm³	
	Water	Air		Water	Air
H-3	0.2	10^{-5}	Cs-137+Ba-137	2×10^{-3}	2×10^{-7}
Be-7	2×10^{-3}	3×10^{-6}	Ba-140+La-140	3×10^{-4}	2×10^{-8}
C-14	3×10^{-3}	10^{-5}	La-140	3×10^{-4}	5×10^{-8}
F-18	0.2	3×10^{-3}	Ce-144+Pr-144	10^{-4}	2×10^{-9}
Na-24	8×10^{-3}	10^{-6}	Pr-143	5×10^{-4}	9×10^{-8}
P-32	2×10^{-4}	10^{-7}	Pm-147	2×10^{-3}	4×10^{-8}
S-35	5×10^{-3}	10^{-6}	Sm-151	8×10^{-3}	3×10^{-9}
Cl-36	4×10^{-3}	6×10^{-7}	Eu-154	4×10^{-4}	2×10^{-9}
A-41	5×10^{-4}	5×10^{-7}	Ho-166	5×10^{-4}	8×10^{-8}
K-42	3×10^{-3}	6×10^{-7}	Tm-170	5×10^{-4}	10^{-8}
Ca-45	10^{-4}	8×10^{-9}	Lu-177	10^{-3}	2×10^{-7}
Sc-46	4×10^{-4}	5×10^{-8}	Ta-182	5×10^{-4}	2×10^{-8}
Sc-47	9×10^{-4}	2×10^{-7}	W-181	7×10^{-4}	10^{-7}
Sc-48	4×10^{-4}	7×10^{-8}	Re-183	2×10^{-3}	4×10^{-7}
V-48	3×10^{-4}	5×10^{-8}	Ir-190	3×10^{-3}	6×10^{-7}
Cr-51	2×10^{-2}	4×10^{-6}	Ir-192	5×10^{-4}	3×10^{-8}
Mn-56	3×10^{-3}	5×10^{-7}	Pt-191	7×10^{-4}	10^{-7}
Fe-55	5×10^{-3}	7×10^{-7}	Pt-193	9×10^{-4}	2×10^{-7}
Fe-59	10^{-4}	2×10^{-8}	Au-196	2×10^{-3}	2×10^{-7}
Co-60	4×10^{-4}	8×10^{-8}	Au-198	6×10^{-4}	10^{-7}
Ni-59	4×10^{-3}	7×10^{-7}	Au-199	2×10^{-3}	3×10^{-7}
Cu-64	5×10^{-3}	9×10^{-7}	Tl-200	10^{-3}	2×10^{-7}
Zn-65	2×10^{-3}	4×10^{-7}	Tl-201	9×10^{-3}	2×10^{-6}
Ga-72	5×10^{-4}	10^{-7}	Tl-202	5×10^{-3}	9×10^{-7}
Ge-71	2×10^{-2}	3×10^{-6}	Tl-204	10^{-3}	2×10^{-7}
As-76	2×10^{-4}	4×10^{-8}	Pb-203	2×10^{-3}	4×10^{-7}
Rb-86	3×10^{-3}	4×10^{-7}	Pb-210+dr.	2×10^{-6}	8×10^{-11}
Sr-89	7×10^{-5}	2×10^{-8}	Po-210	3×10^{-6}	10^{-10}
Sr-90+Y-90	8×10^{-7}	2×10^{-10}	At-211	3×10^{-6}	5×10^{-10}
Y-91	3×10^{-4}	9×10^{-9}	Rn-220+dr.		10^{-7}
Zr-95+Nb-95	6×10^{-4}	8×10^{-9}	Rn-222+dr.		10^{-7}
Nb-95	2×10^{-3}	2×10^{-7}	Ra-226+55%dr.	4×10^{-9}	8×10^{-12}
Mo-99	3×10^{-3}	5×10^{-7}	Ac-227+dr.	3×10^{-6}	4×10^{-12}
Tc-96	10^{-3}	2×10^{-7}	Th-natural	5×10^{-7}	3×10^{-11}
Ru-106+Rh-106	10^{-4}	2×10^{-8}	Th-234+Pa-234	2×10^{-4}	10^{-8}
Rh-105	10^{-3}	2×10^{-7}	U-natural	2×10^{-6}	3×10^{-11}
Pd-103+Rh-103	5×10^{-3}	8×10^{-7}	U-233	3×10^{-6}	3×10^{-11}
Ag-105	4×10^{-4}	7×10^{-8}	Pu-239	3×10^{-6}	2×10^{-12}
Ag-111	5×10^{-4}	8×10^{-8}	Am-241	3×10^{-6}	4×10^{-11}
Cd-109+Ag-109	7×10^{-2}	7×10^{-6}	Cm-242	2×10^{-6}	2×10^{-10}
Sn-113	2×10^{-3}	3×10^{-7}	Any fission mixture (beta, gamma)	10^{-7}	10^{-9}
Te-127	7×10^{-4}	10^{-7}	Any mixture of alpha emitters	10^{-7}	5×10^{-12}
Te-129	2×10^{-4}	4×10^{-8}			
I-131	6×10^{-5}	6×10^{-9}			
Xe-133	4×10^{-3}	4×10^{-6}			
Xe-135	10^{-3}	2×10^{-6}			

signals should be provided during radiation periods.

For radiography which requires the removal of the sealed source from its shielding container a clearly identifiable dummy capsule should be used during any preliminary adjustments and it is essential that the radiographic set-up should be completed before starting irradiation. A radiation detection instrument should be in constant use to verify that the source has been correctly returned to its shielding container at the end of the exposure.

When radiography is carried out away from the normal area, diagrams are to be posted near the area, identifying the source and the steps to be taken by any person finding it.

Unsealed Sources

The choice of radioactive material and suitable processes should be, as far as possible, limited by the contained activity. In considering places of work, special attention should be given to the question of location. Important features of construction, requiring special attention, include cleaning facilities and strength of floors, walls and working surfaces, sinks, furniture, lighting and ventilation. Stress is laid on the ability to wash all surfaces easily. With regard to air contamination, the need for proper ventilation control is emphasized. All operations likely to produce radioactive contamination through production of aerosols should be effected in an air-tight enclosure, kept below atmospheric pressure.

Protective Clothing

Even if only very small quantities of radioactive material are being manipulated, all persons involved should wear adequate protective clothing. This clothing should be clearly identified and not used outside controlled areas.

Special uses of Unsealed Sources

Pumping installations for radon or thoron should be separately housed and the filling of glass capillaries or gold seeds with radon, should be carried out before appreciable quantities of decay products have been formed. Special attention is required to ventilation in rooms used for radon work. Luminizing involving the application of radium and similar isotopes include a number of protective measures, such as glove boxes or extra protective clothing, receptacles vented outside, and periodic surveys by ultraviolet light. Waste disposals need special attention.

The medical use of unsealed radioactive sources presents additional difficulties and it is stressed that the use of them should not be undertaken unless the requirements of competent authorities are met. The use of radioactive isotopes in animal experiments, involves additional risks and needs special supervision.

Permissible Exposure

Whole body exposure:

Blood-forming organs.....300 mrems/week, also gonads, eye lens; skin, 600 mrems/week. E.M. radiation to 3 MeV only 300mr.

Limited portion of the body:

1. Hands, forearms, feet, ankles.....1500 mrems/week in the skin. Less in deeper tissues.
2. Head and neck.....1500 mrems/week in the skin. 300 mrems/week in the lens of the eye. Less than 1500 mrems/week in deeper tissues.

In all these cases the skin dose refers to the significant skin area receiving the highest weekly dose. In exceptional cases in which it is necessary for a person to receive in one week more than the basic permissible weekly organ dose, the unit of time may be extended to 13 weeks provided that the total dose in any organ accumulated during a period of any 13 consecutive weeks does not exceed 10 times the permissible weekly dose.

For exposure of general population the maximum permissible levels outside controlled areas is 10% of the occupational exposure levels. Under the conditions envisaged, however, the regions in which the 10% level might be reached would contain a very small fraction of the population.

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5. TRANSPORTATION OF RADIOACTIVE MATERIAL

Transportation within an establishment
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Waste storage
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TABLE 2

Classification of isotopes according to relative toxicity per unit activity
(Asterisk denotes gamma-emitter)

Class 1. Very high toxicity

Sr–90+Y–90, *Pb–210 (Ra D+E), Po–210, At–211, Ra–226+55 per cent* daughter products, Ac–227, *U–233, Pu–239, *Am–241, Cm–242.

Class 2. High toxicity

Ca–45, *Fe–59, Sr–89, Y–91, Ru–106+*Rh–106, *I–131, *Ba–140+La–140, Ce–144+*Pr–144, Sm–151, *Eu–154, *Tm–170, *Th–234+*Pa–234, *natural uranium.

Class 3. Moderate toxicity

*Na–22, *Na–24, P–32, S–35, Cl–36, *K–42, *Sc–46, Sc–47, *Sc–48, *V–48, *Mn–52, *Mn–54, *Mn–56, Fe–55, *Co–58, *Co–60, Ni–59, *Cu–64, *Zn–65, *Ga–72, *As–74, *As–76, *Br–82, *Rb–86, *Zr–95+*Nb–95, *Nb–95, *Mo–99, To–96, *Rh–105, Pd–103+Rh–103, *Ag–105, Ag–111, Cd–109+*Ag–109, *Sn–113, *Te–127, *Te–129, *I–132, Cs–137+*Ba–137, *La–140, Pr–143, Pm–147, *Ho–166, *Lu–177, *Ta–182, *W–181, *Re–183, *Ir–190, *Ir–192, Pt–191, *Pt–193, *Au–196, *Au–198, *Au–199, Tl–200, Tl–202, Tl–204, *Pb–203.

Class 4. Slight toxicity

H–3, *Be–7, C–14, F–18, *Cr–51, Ge–71, *Tl–201.

TABLE 3

Types of laboratory required

Toxicity of isotopes	Minimum significant quantity	Type of laboratory or working place required		
		Type C Good chemical laboratory	*Type B* Radioisotope laboratory	*Type A* High level laboratory
Very high	0.1 μc	10 μc or less	10 μc– 10 mc	10 mc or more
High	1.0 μc	100 μc or less	100 μc–100 mc	100 mc or more
Moderate	10 μc	1 mc or less	1 mc– 1 c	1 c or more
Slight	100 μc	10 mc or less	10 mc– 10 c	10 c or more

NEW BOOKS

Axial Flow Compressors, Fluid Mechanics and Thermodynamics. By J. H. Horlock, M.A., Ph.D., A.M.I.Mech.E., A.F.R.Ae.S. (189 pp., 104 illus. Butterworth Scientific Publications, 40s.)

Dr. J. H. Horlock is well known to engineers engaged on work connected with axial flow compressors. His book on these compressors is to be welcomed and will prove useful to those concerned with these machines. Engineers who expect to be able to design an axial flow compressor after reading this book will be disappointed, but Dr. Horlock does not set out with this intention. This book goes into the theory of the axial flow compressor, starting with the basic fluid mechanics and thermodynamics of compression. Two chapters follow on two-dimensional cascades, which form the basis of most compressor design data; the first of these outlines methods of predicting cascade performance theoretically, while the second gives details of experimental results, with examples of American and British methods. Three-dimensional flow is not neglected and the relative merits of the radial equilibrium and actuator disc theories are considered. The chapter on characteristics and efficiencies is mainly based on the methods of Howell, showing how sound his original proposals were. More recent ideas are mentioned, but for all their complications it is doubtful whether they give better results.

The different types of stall possible in compressor blade rows are adequately described. Current theories of the mechanism of surging, which still remains a mystery are discussed, but no new suggestions are made. The testing of compressors is dealt with in a short chapter, which mainly details the instruments available for taking measurements necessary to determine compressor performance. The last chapter gives an introduction to supersonic compression, a subject still in its infancy.

In all this Dr. Horlock writes clearly and the text is well supported by many illustrations. It is unfortunate that there is not universal agreement on symbols to be used in compressor work and some readers may find that this makes reading a little difficult, but they should not be deterred on this account. As permissible temperatures in nuclear power stations rise so that gas turbines and steam turbines on gas turbine cycles become more attractive, the axial flow compressor will find more use. Those who wish to understand the fluid mechanics and thermodynamics of this type of machine will find Dr. Horlock's book a sound introduction. Should they wish to delve further into the intricacies of axial flow compressors, a very extensive list of references is included.—F.O.J.O.

Hot Laboratory Equipment. By L. G. Strang, Jr. (2nd edition. Published by the U.S. Atomic Energy Commission, $2.50.)

As stated in the preface, any correlation of this type of information must resolve itself in the form of a catalogue of equipment for use in remote handling. Nevertheless, this "catalogue" is very readable and informative, some 229 items of hot laboratory equipment are explained, with photographs, diagrams, details of application and technical descriptions. Whilst the latter in some instances tend to be rather vague, it would not, of course, be possible to detail such items as the No. 8 Master Slave Manipulators or a remote-controlled quartz fibre micro-balance as these two items alone would require 40 or 50 pages. However, at the end of each handling facility, a reference is quoted giving the potential user a guide as to where he may obtain further details of any described item. A rider has been added to the effect that whilst some of the equipment is available, others cannot be taken as working propositions, but the numerous ideas expressed in the book may give useful guidance to some remote handling problems encountered in the design of such equipment.

Whilst the reports on chemical processing and materials handling equipment are quite numerous, there is very little information on glove boxes, which form an essential part of remote handling.

Mention is made in the preface of a British journal entitled "Remote Handling Equipment" by A. Apperly, A.E.R.E. (ER-1291); this publication is now obsolete and has been superseded by a catalogue of standardized handling equipment held in A.E.R.E. Stores, which should now serve as a source of information on U.K.A.E.A. authorized equipment for remote handling. There is not in existence at present a comparable British journal, and the present publication of "Hot Laboratory Equipment" will serve as a useful guide to those concerned with the design of handling facilities and the problems associated with them, though such a wealth of information could perhaps confuse those whose remote handling problems are comparatively small and incidental to the main path of their specific research.

At the price of $2.50, this edition of "Hot Laboratory Equipment" is a worthwhile addition to the technical library.—L.W.C.

RECENT BRITISH STANDARDS

B.S.1500 : 1958. Fusion Welded Pressure Vessels for the chemical, petroleum and allied industries. Part 1, Carbon and low-alloy steels. (The British Standards Institution, 40s.)

Of uncommon size (133 pp.) for a British Standard, this revision supersedes the provisional (1949) edition as far as carbon and low-alloy vessels are concerned.

Three classes of vessel are recognized according to the stringency of requirements of design, material control, quality of welding, etc. The specification, which is fully illustrated, covers practically every aspect of pressure vessels. Under Design, for example, it deals with corrosion and erosion, types of welded joints, ligament efficiency, cylindrical shells, conical and flat ends, tube plates, openings branches and compensation, manholes, stayed surfaces, bolted flanged connections, jacketed construction supports and internal structures. The other sections, on Manufacture and Workmanship, Inspection and Tests, Materials and Design Stresses and Protective Devices, are equally comprehensive. New features are appendices giving recommended practice for vessels required to operate at low temperatures, and a series of examples illustrating the application of the various formulæ and rules.

Two other BS recently issued are also of interest in the nuclear field:

B.S.1501 : 1958. Steels for use in the Chemical Petroleum and Allied Industries (25s.) and

B.S.1510 : 1958. Low temperature Supplementary Requirements for B.S.1501.

The first of these two specifications covers plates, sections and bars, forgings, castings, and bolting bars in a variety of carbon and alloy steels, giving compositions and required mechanical properties. Appendices give a key to the system of reference numbering of steels, and comparable British and American specifications. The second specification gives additional requirements for low temperature working down to −190°C.

Technical Papers and Publications

Institution of Mechanical Engineers in conjunction with The British Nuclear Energy Conference

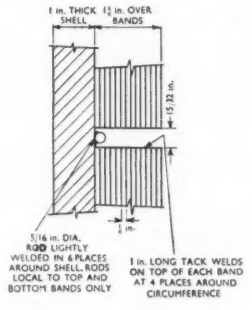
Experimental Investigation into the Stress Distribution in a Band-reinforced Pressure Vessel. By K. G. Mantle, B.Sc., A.M.I.Mech.E., N. Marshall, M.A., P. J. Palmer, M.Sc., Ph.D.

In a cylindrical pressure vessel with domed ends, the limit of pressure is set not by the ends but by the hoop stresses in the cylindrical portion, which, for any given pressure, must be considerably thicker than the domed ends. Plate thickness is limited by various considerations—difficulty of welding, difficulty of applying absolutely reliable non-destructive test methods to thick plates, and increased difficulty in producing absolutely sound plates as the thickness increases.

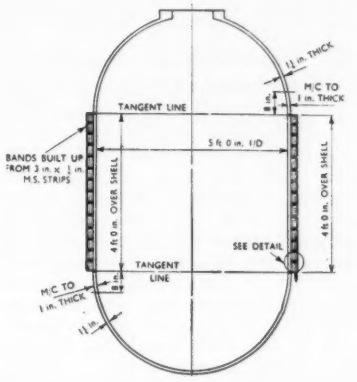
Reinforced vessels have of course previously been made, but in many cases they have been of the fully layered type in which the reinforcement shares in the longitudinal as well as the hoop stresses.

The method proposed by the authors of this paper is to use relatively thin plates for the barrel and to reinforce with multi-layer bands; the ends and barrel being proportioned so as to carry the longitudinal stresses, the reinforcing bands to assist with the additional hoop stress. The use of multiple layers of comparatively thin metal for the bands simplifies the problems of welding and inspection. The thinner barrel also means that larger plates are available and the amount of welding is reduced.

Such a vessel has been built and tested to destruction by John Thompson, Ltd., with which organization the authors are associated. The vessel in question is, in effect, a model, approximately 1/10th full size, of a reactor vessel; actual dimensions are 9 ft overall length and 5 ft diameter. The wall and band thicknesses are not to scale; it was considered desirable to wrap a comparable number

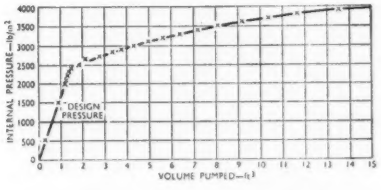

1 in. THICK SHELL
1½ in. OVER BANDS
15.32 in.
5/16 in. DIA. ROD LIGHTLY WELDED IN 6 PLACES AROUND SHELL, RODS LOCAL TO TOP AND BOTTOM BANDS ONLY
1 in. LONG TACK WELDS ON TOP OF EACH BAND AT 4 PLACES AROUND CIRCUMFERENCE

of bands instead of a comparable thickness. The band was fabricated from boiler quality 28-32 ton mild steel, 1 in. thick, and the ends pressed from 1¼ in. thick plate, machined to 1 in. thick for 8 in. from the tangent line (i.e. the junction of band and hemisphere). Reinforcement was 3 × ⅛ in. M.S. strip, and particular care was taken in the fitting, both band and vessel being shot-blasted and the bands coated with colloidal graphite. Bands were pulled down tight


1¼ in. THICK
M/C TO 1 in. THICK
TANGENT LINE
5 ft 0 in. I/D
BANDS BUILT UP FROM 3 in. × ⅛ in. M.S. STRIPS
46.0 in. OVER SHELL
SEE DETAIL
TANGENT LINE
M/C TO 1 in. THICK
1¼ in.

General arrangement of test vessel.

by a circumferential chain thus applying a radial loading. (Had the tightening been done by applying tension, it was pointed out in the discussion, it would have been possible to obtain a 2 : 1 ratio of tensile stress on opposite sides of the band.) Each band was cut 2-3 in. short of the required length and a filler piece cut to size and welded in, after pulling down. Particular care was taken to see that the first layer of each band was not welded to the vessel, by using a backing strip of 0.005 in. thick glass tape. The gap between the bands, due to normal working tolerances observed during the manufacture of the vessel was estimated at 0.002-0.003 in. and, although large in proportion to the scale, they would give pessimistic results.



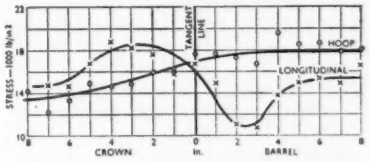
(Above) Water volume pumped plotted against pressure, in test to destruction.

(Left) Detail of bands.

Tests were carried out in four stages. After cycling to 1,000 p.s.i. four times to allow setting of the vessel and electrical strain gauges, hydraulic tests were taken up to 1,000 p.s.i., gauges being read at every 200 lb. This test was then repeated from 0-2,000 p.s.i. The end bands were then removed and replaced with 6-in. bands overlapping the tangent line, and a further series of strain readings was taken local to the tangent line, up to 1,000 p.s.i. Finally, the vessel was tested to destruction, the volume of water pumped being plotted against the increase in pressure.

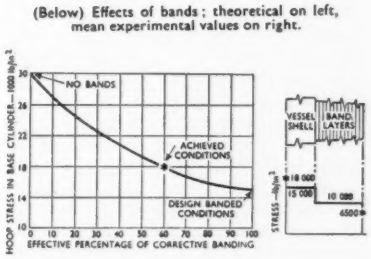
Comparing actual test results with calculated stresses, as one would expect, the band reinforcement is not fully effective. Nevertheless, the general stress level was maintained within acceptable limits, i.e., within about 20% of calculated stresses.

The maximum pressure reached was 3,940 p.s.i., after general yielding at 2,350 p.s.i., and random band breakage from 3,140 p.s.i. onwards. Failure was unspectacular, it was impossible to raise the pressure beyond 3,940 p.s.i. due to general yielding, although bursting had not occurred. The large safety factor on the design pressure is considered very satisfactory, and shows that the effects of gaps between the bands and of discontinuities (such as at the tangent line) have largely been eliminated.



(Above) Hoop and longitudinal stresses local to tangent line after rebonding.

(Below) Effects of bands; theoretical on left, mean experimental values on right.



Symposium of the Powder Metallurgy Joint Group of the Institute of Metals and the Iron and Steel Institute.

Bonding in Carbides, Silicides, and Borides, by D. A. Robins, B.Sc., Ph.D., A.I.M., A.Inst.P. (Communication from the Staff of the Research Laboratories of The General Electric Co., Ltd., Wembley, Middlesex.)

The hypothesis that many of the properties of the transition metals, their alloys, and their compounds can be understood in terms of a relationship between the co-ordination of the metal atoms and the number of bonding electrons per atom, is applied to the carbides, silicides, and borides of the transition metals of Groups IVA, VA, and VIA. The crystal structure and stability of the carbides can be satisfactorily explained on the basis of electron concentration, but a complete understanding of the bonding in the silicides and borides is more difficult. In the silicides the metal-silicon bonding, which is metallic in character, becomes of increasing importance as the silicon content is increased, and in the disilicides no direct metal-metal bonding remains. The ability of boron to form strong boron-boron bonds is important in the borides, and the metal-metal co-ordination would appear to be of only secondary importance. The practical significance of the principles put forward is discussed.

The Fabrication and Properties of Chromium-Alumina and Molybdenum-Chromium-Alumina Cermets, by J. B. Huffadine, L. Longland and N. C. Moore.

After a brief review of the literature, various methods for preparing chromium-alumina and molybdenum-chromium-alumina cermets are described. The properties of such materials are discussed and an indication is given of their possible applications.

The Fabrication and Properties of Uranium Oxide-Iron Cermets, by W. J. Wright, R. B. Gibbon and J. Williams.

Cermets of iron-uranium dioxide, containing up to 30 vol.-% UO_2 have been rolled to rod. Although the cores rolled centrally along the length, the core was distorted in section owing to stiffening of the core relative to the sheath as the temperature dropped during rolling. The UO_2 particles were fragmented during rolling and formed as "stringers" along the direction of rolling, seriously weakening the structure transversely.

By extrusion at 1,200°C, cermets containing up to 50 vol.-% UO_2 were satisfactorily fabricated. The extrusion pressure increased sharply above 35 vol.-% of ceramic and when large reductions in area were taken. The extrusion characteristics do not conform to isotropic plastic extrusion nor to a pure viscosity effect; the influence of the dispersed particles on metal flow is explained by a strong interference effect between particles and the metal during flow. The properties of the extruded rods were good; the core density was 90-95% of theoretical, decreasing slightly with increasing ceramic content; there were no obvious directional properties in the core, nor was the ceramic fragmented as in rolling. The characteristic "tail-end defect" of the extrusions was partly corrected by using shaped sealing plugs.

The High-temperature Properties of Ceramics and Cermets, by E. Glenny, B.Sc., A.I.M. and T. A. Taylor, M.Sc., Ph.D., A.I.M.

It has been recognized for some time that, with progressive increase in the working temperature of gas turbines, metallic alloys may no longer be adequate for rotor or stator blading. The use of more refractory but more brittle materials, i.e. ceramics and ceramic-metal mixtures (cermets) has been suggested. The paper is concerned with the evaluation of the major properties involved, viz. creep strength, fatigue strength, resistance to thermal fatigue (i.e. to repeated thermal shocks), oxidation-resistance, and impact-resistance. The materials evaluated include oxides, oxide-metal cermets, carbides, carbide-metal cermets, molybdenum disilicide, and silicon nitride. The equipment for determining the effects of alternating and steady mechanical stresses up to 1,200° C is described. The relative merits of the test materials are discussed. It is concluded that the resistance to thermal fatigue and to impact of the ceramics and cermets is inferior to that of metallic alloys in current use.

Recent Developments in the Field of Silicides and Borides of the High-melting-point Transition Metals, by R. Kieffer and F. Benesovsky.

The binary systems of silicides of the high-melting-point transition metals are now well understood, except for the hafnium-silicon system. Research since 1954 is reviewed, with particular reference to the compound Me_5Si_3 and its position in the silicide systems. Reference is also made to the pseudo-binary and pseudo-ternary silicide systems.

The structures of many of the intermetallic phases in the binary boride systems have now been determined, but complete equilibrium diagrams still remain to be established in some cases. New tentative diagrams are given for the systems vanadium-boron, niobium-boron, and tantalum-boron, and structures are suggested for the borides V_3B_2, Nb_3B_2, and Ta_3B_2 with the *T*2 structure (isostructural with U_3Si_2).

Ternary alloys of the systems *Me*-Si-B are of great interest, not only structurally but also for practical reasons. The complete systems *Me*-Si-B of Group VI (Mo-Si-B and W-Si-B) have accordingly been studied by X-ray, thermal-analysis, and micrographic methods. The system Cr-Si-B has been determined and attention is directed to the possible commercial applications of certain alloys containing additions of metals of the iron group, in particular nickel, for sprayed coatings resistant to liquid aluminium.

The question of cementing silicides and borides with metals and alloys is discussed theoretically. The character of the silicide or boride system in question and the behaviour of the intermediate phase in relation to the bonding material are of decisive importance for the selection of the latter. Only very limited data are to be found in the literature on the relationship of silicides and borides to different metals and alloys. Alloys based on TiB_2, ZrB_2, $MoSi_2$, and WSi_2, impregnated with numerous metals and alloys, have been prepared. Their structures have been studied and the technical suitability of various combinations is discussed on the basis of their technological properties.

The Oxidation of Zirconium Carbide in High-temperature Combustion Gases, by W. Watt, B.Sc., A.R.I.C.

The reactions of sintered zirconium and titanium carbides have been studied in simulated rocket combustion gases at surface temperatures of about 2,250°C. Under these conditions zirconium carbide is oxidized according to a parabolic law owing to the formation of an adherent oxide film. No oxide film is formed on titanium carbide under the same conditions, and it decreases in weight and dimensions at a relatively rapid rate.

The Use of Radioactive Isotopes for the Investigation of Sewage Treatment Plant, by S. G. Burgess, Ph.D., B.Sc., F.R.I.C. (Scientific Adviser to the L.C.C.) and A. F. Green, B.Sc., F.R.I.C. (Principal Scientific Officer, L.C.C. Public Health Dept.)

The use of isotopes has proved very satisfactory for full-scale investigations, including time of retention of sewage in settling tanks and flow over inlet and outlet weirs. Bromine-82 and chromium-51 have been used as tracers, in the form of ammonium bromide and sodium chromate respectively. For preliminary work phosphorus-32 was used.

The ratemeter used was the Ekco N522A, but the counter heads were built in the laboratory; a type being developed which would operate at distances up to ¼ mile from the ratemeter; a necessity for this type of work. Up to six counter heads were in simultaneous use for certain measurements.

Developing the BWR

COMPREHENSIVE long-term proposals for intensive development of the boiling water reactor have been put forward in the U.S., by General Electric. The overall plan consists of two separate programmes, known as "Operation Sunrise" and "Operation Know-how."

"Sunrise"

This is intended to accelerate progress in development of the boiling water reactor to make it competitive with conventional generating plant and would be divided into five stages.

Stage 1, the development of "first generation" boiling water reactors, to act as a technological base, has already been accomplished, representative plants being the EBWR developed by Argonne, and G.E.'s own reactor at Vallecitos, operated by G.E. and Pacific Gas and Electric Co., as well as the Dresden station under construction for Commonwealth Edison, to operate in 1960.

Stage 2, the "developmental" stage, would involve the construction of a number of small- and medium-sized reactors by 1962 each intended to solve a different technological problem. These include:

1. A 25 MW reactor to study cost reduction by reduction in the physical size.
2. A 25 MW reactor to prove the possibilities of doubling power output per unit volume of core.
3. A 50 MW nuclear superheater used as a "hook-on" to an existing BWR plant.
4. A 100 MW (or larger) plant to test power density limits obtainable in a medium-sized reactor.
5. The 50 MW reactor which G.E. is designing for the Pacific Gas and Electric's Humboldt Bay station.

Stage 3, the "evolutionary" stage, would consist of three large-scale plants for operation by 1965, incorporating the improvements made in Stage 2. They include a 100 MW natural circulation plant, a 200 MW plant with forced circulation, and a 325 MW plant with superheater.

Stage 4 scheduled for 1970 would have three "target" plants with outputs of around 450 MW with capital costs of $175-$225/kW and fuel costs of 1.7-2.2 mills/kWh.

Stage 5. No concrete proposals are made for Stage 5.

The estimated cost of "Sunrise" would be $128M over a period of seven years excluding the cost of the competitive plants.

"Know-how"

The second plan proposes the quantity production of small packaged power plants. Construction of up to 50 of these (of which G.E. would be prepared to furnish 25) would, in the words of Mr. Francis K. McCune (G.E. vice-president and general manager of the Atomic Products Division). . . "provide this country with the finest field experience network in the world, as well as a valuable facility for carrying out advanced tests of fuels and components."

Further advantages of the plants, which should be built within easy driving distance of population centres, would be the increased understanding of the community in general of atomic power, the opportunities for formulation of realistic health ordinances and safety regulations, and closer relationships with insurance companies.

The packaged plant, based on the experience gained with the Vallecitos reactor, would have an output of 5 MW, and cost $4-4.5M.

High Temperature Reactor Development Associates Inc.

PLANS for the development of a high-temperature gas-cooled reactor have been announced by the High Temperature Reactor Development Associates Inc., a new non-profit organization consisting of some 40 U.S. privately owned utility companies. The project, sponsored by the Philadelphia Electric Co., has submitted a formal proposal to the A.E.C. in response to the Commission's invitation to industry, issued in September, to undertake the design of a prototype high-temperature gas-cooled power reactor. The Bechtel Corporation has been named as engineer-constructor, and the General Atomic division of General Dynamics Corporation, who have been investigating the design for the past two years, will be responsible for the nuclear plant. The turbine and electrical portion will be supplied by Westinghouse Electric Corporation. The estimated cost is $24.5M, which would not include research and development costs (estimated at $14.5M) for which Government assistance is requested.

A list of the companies comprising the H.T.R.D.A. is appended. Those marked with an asterisk are members of the Rocky Mountain - Pacific Nuclear Research Group which has already been associated for some time with General Dynamics in the development.

Preliminary Details

Heat output	115 MW
Electrical output	40 MW
Fuel	Compact of carbides of U and Th with graphite, in graphite or metal cans.
Coolant	Helium
Inlet Temp.	662°F
Outlet Temp.	1,382°F
Coolant Flow	440,000 lb/h
Steam conditions	1,450 p.s.i. 1,000°F
Steam flow	367,000 lb/h

Design

As would be expected, complete design details are not available but a few of the main particulars are given in the table. The most interesting feature of the design (apart from the gas temperature of 1,382°F) would appear to be the fuel elements. Present proposals indicate a compact of graphite with carbides of U^{235} and thorium canned in long graphite cylinders of large diameter. In order to meet the five-year time scale for completion it is possible that the initial elements will have metallic canning.

The advantages of helium cooling and graphite canning hardly need to be stressed. At the temperature of operation it is stated that a considerable proportion of the heat transfer between the compact and the can will be by radiation, and avoid the necessity for a large number of small elements to obtain the required heat transfer rate.

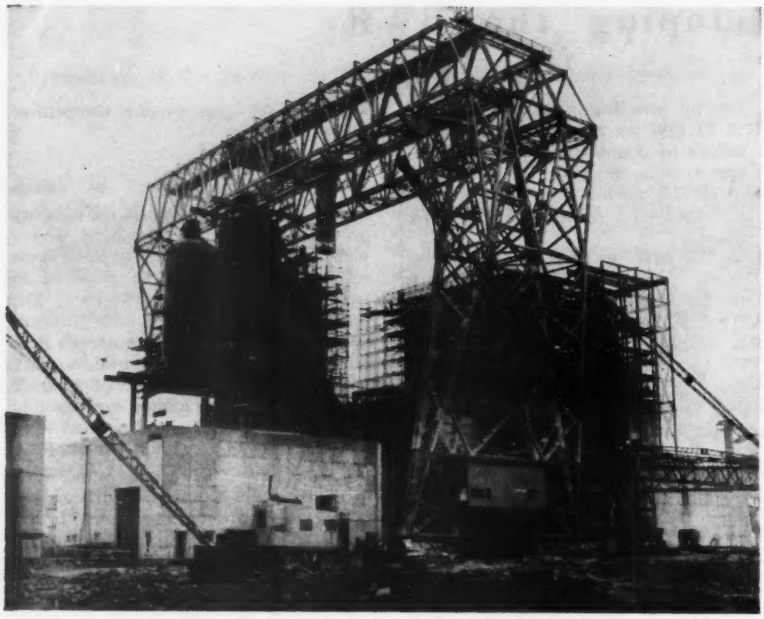
From the standpoint of control and safety it is pointed out that this homogeneous mixture of fuel and moderator gives a high heat capacity and a rapid-acting negative temperature coefficient. Also, the graphite side and bottom reflectors, which normally operate at inlet temperature, form a heat sink to which the core can radiate shut-down heat in case of a coolant failure.

H.T.R.D.A. Members

Alabama Power Company; Arizona Public Service Co.*; Atlantic City Electric Co.; Baltimore Gas and Electric Co.; California Electric Power Co.*; Central Illinois Electric and Gas Co.; Central Illinois Light Co.; Central Illinois Public Service Co.; Central and South West Corp.; Central Louisiana Electric Co.; Cincinnati Gas and Electric Co.; Delaware Power and Light Co.; Detroit Edison Co.; Hawaiian Electric, Ltd.; Idaho Power Co.; Illinois Power Co.; Iowa Power and Light Co.; Iowa Public Service Co.; Kansas City Power and Light Co.; Kansas Power and Light Co.; Kentucky Utilities Co.; Missouri Public Service Co.; Montana Power Co.; New York State Elec. and Gas Corp.; Niagara Mohawk Power Corp.; Pacific Gas and Electric Co.; Pacific Power and Light Co.*; Pennsylvania Power and Light Co.; Philadelphia Electric Co.; Portland General Electric Co.*; Public Service Electric and Gas Co.; Public Service Co. of Colorado*; Public Service Co. of New Mexico*; Puget Sound Power and Light Co.; Rochester Gas and Electric Corp.; St. Joseph Light and Power Co.; San Diego Gas and Electric Co.; Sierra Pacific Power Co.; Southern California Edison Co.; Utah Power and Light Co.*; Washington Water Power Co.*

* Indicates member of the Rocky Mountain-Pacific Nuclear Research Group.

World News



The Goliath crane erecting boilers for No. 1 reactor at the Bradwell nuclear power plant shows the scale of development at the end of the second year on site. The reactor is expected to go critical mid-1960.

International

THE CANADIAN GOVERNMENT have offered to supply the I.A.E.A. with 3 tons of natural uranium free of charge. This follows the Agency's recent request for tenders for the supply of nuclear fuel. Other tenders were received from the United States (submitting a bid on behalf of Davison Chemical Company at $54.34 per kilogram) and Belgium (a bid of Société Générale des Minerais at 1,700 Belgian francs [equivalent to $34.00]). The monetary value of the Canadian gift is $100,000.

WORLD radioactivity warning system has been drawn up by the International Civil Defence Organization following a recommendation at a conference in Geneva early in 1958.

A PANEL concerned with the problem of pollution of the seas from peaceful uses of nuclear energy, met at the I.A.E.A. headquarters in Vienna on December 4. Under the chairmanship of Dr. H. Brynielsson, director-general of the Swedish Atomic Co., the panel was comprised of scientists from Canada, Czechoslovakia, France, India, Japan, Netherlands, Sweden, United Kingdom, U.S.A. and the U.S.S.R.

I.A.E.A. OFFICIALS recently visited Poland at the invitation of the government. They include the chairman, Ambassador C. Bernardes, Mr. S. Cole, Dr. P. Jolles, Prof. H. de Laboulaye and Dr. Karl Gruber. The party visited a research reactor near Warsaw and a cyclotron recently completed at Cracow.

United Kingdom

LAST OF THE FOUR reactors at Calder Hall went critical on December 10. The reactor will be gradually run up to full power during the coming months.

FINANCIAL SECRETARY to the Admiralty, Mr. R. A. Allan has reported in the Commons that good progress was being made in adapting the submarine Dreadnought to accommodate U.S. nuclear machinery.

CONCERN of medical officers and public health officials at their lack of powers to control dangers resulting from the use of radioactive material was made evident at a symposium on radiation hazards held by the Royal Society of Health recently in Wolverhampton. It was pointed out that no rules have yet been formulated by an official source for local authority guidance. Officials responsible did not even know the amount of radioactive material in their areas and as the AEA were the sole source of radioactive material, they should be required to notify local authorities of deliveries made.

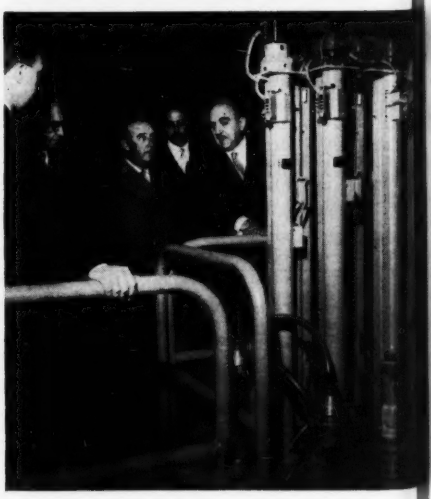
FAO EUROPEAN meeting on the Use of Ionizing Radiations for Food Preservation, held recently at Harwell was attended by 179 representatives of 17 European countries, 22 observers from four non-European member governments and 14 international organizations. The purpose of the meeting was to survey the present status of food irradiation, make a critical evaluation of the potentialities of this new technique for European countries and consider the need for, and possibility of organizing, international co-operation in research on food irradiation in Europe.

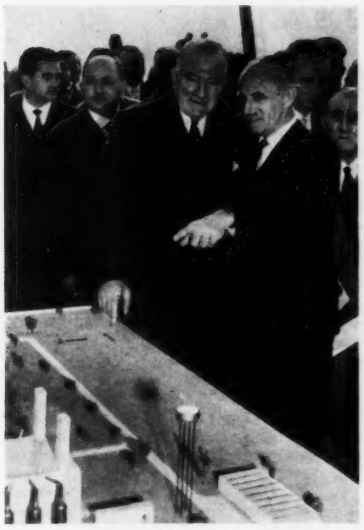
AT COMMITTEE STAGE of the Licensing and Insurance Bill, Opposition concern was expressed at the principle of private industry owning reactors. Lord Mills agreed to an amendment which sought to provide that all claims for injury or damage which had been established should be met by the Exchequer, and that license conditions requiring reimbursement in whole or in part from the licensee would be considered, also that the proposed 10-year period would be reviewed.

ISOTOPE SCHOOL at Harwell have had their 1,000th enrolment. He is Mr. B. H. Court, a refinery chemist from Fawley, Hants.

MINISTER OF COMMERCE for Northern Ireland, Lord Glentoran, said recently in the Northern Ireland House of Commons that he had decided, for the present, to forgo the idea of erecting a proposed nuclear power station in the western Lough Neagh area. It is considered that a coastal site would be preferable.

General Franco on the bridge of Spain's first reactor at the inauguration ceremony recently. The reactor, at Moncloa near Madrid, is a 3 MW swimming-pool type supplied by International General Electric.





Following the laying of the foundation stone at Latina, Ing Enrico Mattei, president of AGIP Nucleare, placed a symbolic parchment into a concrete pouring skip. (Right) Sir Claude Gibb, chairman and managing director of N.P.P.C., points out features of a model of the 200-MW station to Lord Mills, Minister of Power.

Australia

RUM JUNGLE report that a new deposit of uranium ore has been discovered. First indications suggest a deposit of high-grade uranium ore but it is not possible to estimate the extent of the new find without further exploration.

British Guiana

PLAN to provide a nuclear power plant at a cost of about £5 million has been submitted to the government by the Mitchell Engineering Group.

China

IT IS REPORTED that an experimental reactor has been built at the Nankai University at Tientsin.

Denmark

DR2—a 5-MW light water moderated and cooled tank-type reactor at Risø is still bedevilled with welding trouble. A year ago leaks were discovered in the main tank. Now another leak in one of the graphite reflector cells (or cans) has led to a further examination of the other reflector cells. Only four out of 20 were discovered to be in order. The cost of repair is estimated at £3,000.

France

ONE OF SIX Yugoslav nuclear workers died recently in the Curie Hospital in Paris after being involved in an accident at the Yugoslav Institute of Nuclear Studies at Vinca, near Belgrade. The other five are still undergoing treatment.

India

MR. NEHRU has stated that talks have been in progress with nuclear power plant manufacturers with a view to erecting plants capable of producing 250 MW during the third five-year plan which begins in 1960.

Italy

THE FOUNDATION STONE for the first nuclear power plant in Italy was laid at Borgo Sabotino, near Latina, on November 20, by President Gronchi. Lord Mills, U.K. Minister of Power, and Signor Bo, Italian Minister for Industry and Trade, were present. Built by the Nuclear Power Plant Co. of Britain, the plant will cost over £20 million and will produce 200 MW. It is expected to commence operation in 1962.

A STUDY COMMITTEE has been formed to investigate the possibilities of building a 10-MW nuclear power plant in the immediate vicinity of Rome to supply power for the railways. Members of the committee are Prof. A. M. Angelini of CNRN, Mr. A. Montani of ACEA and Mr. R. Righi of the State Railways. Letters calling for prospectuses of technical detail on small and medium plants have already been sent by the State Railways to various British and American firms.

MAJOR CORPORATIONS concerned with the industrial applications of nuclear power, together with a number of scientists and engineers, have established an association called "Italian Nuclear Energy Forum."

PRESIDENT OF SENN, Prof. C. Matteini has returned from the United States after meeting the representatives of AEC, General Electric and International General Electric. Prof. Matteini's visit was in connection with the fixed-price contract for the design and construction of the 150-MW nuclear power plant at Punta Fiume by General Electric.

Japan

FUJI ELECTRIC are negotiating an agreement with the General Electric Company of England for technical co-operation on nuclear power generation. This agreement will be subject to the approval of the Japanese government.

Netherlands

MR. STAF, the Defence Minister, has stated in a memorandum that the possibility of constructing a nuclear-powered submarine at an estimated cost of £10 million is being investigated.

COUNCIL to advise the government on nuclear energy is to be established, according to a recent official report. The main body concerned with nuclear development in the Netherlands is Reactor Centrum Nederland, a consortium of some 50 Dutch companies.

South Korea

MINISTRY OF EDUCATION has announced that an open pool-type reactor is to be bought from an American company.

Switzerland

COUNCIL OF CERN approved contributions from the 12 member states totalling 55 million Swiss francs for the 1959 budget. The first of the association's two particle accelerators, a 600-MeV synchro-cyclotron, came into operation on August 1, 1957, and the second, a 25-GeV proton synchrotron, will be finished in 1960.

DR. W. ZUNTI, scientific head of Reaktor A.G., was elected president of the Swiss Society of Nuclear Energy Scientists at the inaugural meeting held recently in Berne.

Col. Williams, a nuclear power adviser to the U.S. Army's Chief of Engineers, explains the operation of the U.S. Army's package power plant at Fort Belvoir to two Japanese visitors, Hayato Ikeda (left), Japan's State Minister, and Kiichi Miyazawa, a member of the Japanese House of Councillors.

U.S.A.

AEC COMMISSIONER, Mr. J. F. Floberg, speaking at the "Atoms for Power" conference at the University of Missouri at Columbia recently summarized the U.S. power reactor demonstration programme in which the AEC underwrites part of the cost of industrial projects. Contracts have been negotiated with: Yankee Atomic Electric for a 134 MW(E) pressurized water powerplant at Rowe, Mass., Power Reactor Development for a 100 MW(E) fast breeder powerplant at Monroe, Mich., Consumers Public Power District for a 75 MW(E) sodium graphite plant at Hallam, Neb., Rural Co-operation Power Association for a 22 MW(E) boiling water plant at Elk River, Minn. The Commission is also negotiating with Chugach Electric Association for a 10 MW(E) sodium-D_2O plant in Alaska, City of Piqua, Ohio, for a 11.4 MW(E) organic moderated plant, Northern States Power for a 62 MW(E) boiling water plant at Sioux Falls, S. Dak. (now agreed), Carolinas Virginia Group for a 17 MW(E) heavy water-cooled and moderated plant, Pennsylvania Power and Light for the initial research and development for a 70-150 MW(E) aqueous homogenous plant and the East Central-Florida West Coast Group for a 46 MW(E) gas-cooled heavy water-moderated plant. Both the industry and the Government had considerably increased their expenditure over the past few years with the AEC spending about $95 million a year and industry about $40 million.

PEACEFUL ATOM and the Chemical Industry was the title of the talk given by Dr. W. F. Libby, commissioner of the AEC at the 8th semi-annual meeting of the Manufacturing Chemists' Association in New York. Dr. Libby pointed out the strides industry had made over recent years in the production of nuclear material. In 1955, for example, the AEC asked for tenders to supply all of its zirconium metal and by-product hafnium, for a five-year period. Then private industry was supplying about 200,000 pounds a year, but by the time the contracts were negotiated the AEC requirements had increased to nearly 10 million pounds. This meant that the contract had to be split among three firms, each supplying two million pounds of zirconium metal a year, for five years, at the average cost of $14 million a year. The AEC also have contracts for half a million pounds of beryllium at an average cost of $47 a pound.

NUCLEAR FUEL processing symposium formed part of the 51st annual meeting of the American Institute of Chemical Engineers. Mr. L. C. Burman said that major chemical companies would start processing nuclear fuels when a reasonable service charge was possible. He suggested that the AEC should abandon its price ceiling or re-evaluate the daily service charge. Sites for nuclear processing plants should be provided and the responsibility for storage and disposal should be undertaken by the Government.

KANSAS STATE COLLEGE are joint sponsors with the AEC of a Midwest Industrial Radioisotope Conference to be held on February 25-26, 1959, at Kansas State College, Manhattan, Kansas.

NOTICE has been given of proposed issuance of permits by the AEC to North Carolina State College for a low-power reactor, University of Arizona for a low-power reactor and Cornell University for a dual-core reactor.

PROPOSALS for a design study for a heavy water moderated powerplant have been selected by the AEC and a contract is being negotiated with Sargent and Lundy, of Chicago.

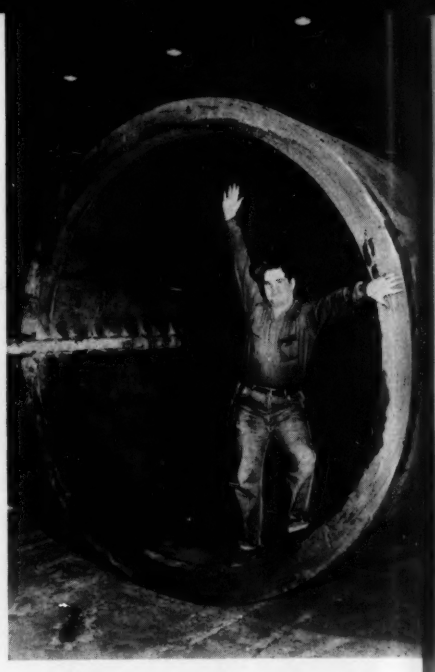
DISCUSSIONS for a suitable site at Piqua, Ohio, for the organic moderated reactor to be built by Atomics International are still taking place.

MORE THAN 50 companies have made a joint proposal to the AEC to construct a gas-cooled reactor plant of 30 MW(E). The AEC are to provide $14,500,000 for research and development. They will waive nuclear fuel charges for a five-year period.

AN ACCIDENT which damaged a small experimental reactor occurred recently at the National Reactor Testing Station at Idaho Falls, where the aircraft nuclear propulsion laboratories are located. AEC announced that a control failure resulted in a small excursion which damaged fuel elements in the core.

LOW-POWER, privately owned, reactor has recently gone into operation at the NDA-Pawling Laboratories, a facility of Nuclear Development Corporation, White Plains, New York State.

GRANTS TO 30 American colleges and universities totalling $326,510, for assistance in equipping their laboratories for training in nuclear technology, have been made by the AEC. This now takes the total of grants made, since the scheme was started in October, 1957, to $1,493,990.



Shown here is a section of the N.S. "Savannah" reactor pressure vessel after it had been formed at the Barberton, Ohio, works of the Babcock and Wilcox Company. The reactor is of the pressurized water type, light-water moderated and cooled, fuelled with low enrichment uranium dioxide rods clad in stainless steel. The design has been dictated largely by the objective of a long core reactivity lifetime. This has been estimated to be 600 operating days at design power which is 74 MW heat.

ADDITIONAL SAFEGUARDS in the handling of sizeable amounts of special nuclear material are now required by the AEC. Licensees subject to this ruling are those authorized to possess more than 500 g of contained uranium-235, 300 g of plutonium and 300 g of uranium-233.

ARIZONA'S first reactor, a 10-30-kW TRIGA supplied by General Atomic and installed at the University research centre, went critical on December 5.

Queen Frederika and her daughter, Princess Sophie, of Greece being shown the Nuclear-Chicago subcritical training reactor which is shortly to be shipped to the Democritus Nuclear Centre near Athens. On the left are Dr. O. K. Neville and Mr. J. M. Phelan of Nuclear-Chicago and extreme right, Mr. J. F. Floberg, AEC Commissioner.

Orbits in Industry

WEDGED into the crowd at the housewarming of the new premises of the Superheater Company, we fell to musing in our usual absent-minded way, instead of making polite conversation—a bad social fault, but one which has persisted, despite spanking in our youth. The subject of our musings, if one may dignify them by that term, was, strangely enough (for it might just as easily have been Chinese metaphysics or the blonde in the corner), superheaters, and the number of people who still think of them as loops of gas-pipe popped into a boiler somewhere as shown in the 1910 textbooks (and far too many modern ones, for that matter). In a modern boiler, the superheater is about half the boiler—and the hot half, too—and its design can be nearly as dicey as that of a reactor. It is true that the gas stream is not radioactive, but neither is it clean. And if the coal changes (and this is not impossible) so that the fly-ash is just nicely molten and about to solidify at the temperature of the superheater zone, the tubes are rapidly covered with stuff that sticks like filings on a magnet, and is probably slightly softer than vitreous enamel, but not much.

Tough Assignment

If any of you feel that the average boiler designer has a soft number, read the papers presented at the recent symposium on the work of the Boiler Availability Committee, if you didn't go to the actual Institute of Fuel meeting. Thomas Hobbes once said that the life of man was ". . . solitary, poor, nasty, brutish and short. . . ." Covered with molten slag at the furnace end, with bonded deposits in the middle zones and corrosive substances at the cool end, the life of a tube is poor, nasty and brutish all right. Why it is not short as well is a minor miracle in which the Boiler Availability Committee, as well as the boiler designer, have played no small part.

Familiarization

The scheme put forward by Mr. Francis K. McCune, vice-president of General Electric (and *please* don't confuse it with Britain's General Electric Co., Ltd.—it makes them both so cross), for intensive development of the boiling water reactor (page 37, this issue) by dotting up to 50 small plants all over the U.S., would have other effects besides piling up the nickels in G.E.'s piggy-bank. One important result would, of course, be the opportunities for training reactor operating teams. Not the least important, however, would be another suggestion by Mr. McCune, that by locating the plants within easy driving distance of population, the public could visit them and gain an increased understanding of nuclear energy, to get it out of the "mystery" realm.

Tangent's own personal opinion is that the sooner the public are educated (or even "familiarized" although it's such a horrid word) in nuclear matters, the better. Then when a lid came off a few millicuries of isotope in transit, it wouldn't make large spaces in even the responsible papers, and a popped-off paint can in a bonfire of rubbish will not make EXPLOSION IN A-PLANT banner headlines, and have people wondering whether it's safe to use milk in their tea. And the small plants proposed would do a great deal in this direction. It is possible to visit Calder, but it is rather an awe-inspiring place for the layman, unlike these small pint-size chaps that one almost feels could be picked up and patted, like a Teddy bear compared with a grizzly.

Not that we would necessarily advocate the construction of plants for this purpose. Public relations at over a million pounds a bash would come pretty high. But it is a nice thought, a lovely pipe-dream, to think of Mom, Pop and Junior belting off in the family car (or cars?) for a jolly picnic at the local atom-plant . . . "a reactor excursion" shorn of its usual sinister meaning.

More-than-Oriental Splendour

Overheard on a bus passing down Grosvenor Place:—

"What on earth is that Place?"
"New A.E.I. office building, I think."
"Golly! Where do you take off your shoes?"

DR. FINAGLE'S LAWS—7

Law of Beams (1)

Any beam designed, in the project stage, to greater than 50% efficiency will be so overloaded as to require re-design when final loading is assessed.

Rise of the Robots

From one point of view, our recent visit to the Computer Exhibition was unproductive of results. The Tangential abacus needed a new bead or two—one row has been running very hot lately—but it was a discontinued model, and there is nothing for it but rebushing and decarbonizing the old beads. As an opportunity to see, at first hand, the impact of computers on mankind, however, it was an unqualified success. Not only did most of the new race of chaps that has sprung up talk like computers, with their jargon of "bits," "delay lines," and "simultaneous print-out," some of them, to our jaundiced eye, are beginning to look like them, and one almost expects to see them open their mouths and produce yards of paper tape, punching it with their teeth as they go.

We do not, however, seem to have gone as far as they have in the U.S., in this machine-ousts-man business. A recent A.S.M.E. programme of a forthcoming meeting of the Aviation Division lists one participator as the "Chief Human Engineer" of a certain corporation, giving one the impression that the Chief Electrical Engineer is probably built up of printed circuits. As it seems high time that the general inferiority of mankind should be put on record, we offer the following:—

BALLADE OF HUMAN INFERIORITY

At counting, I'm no wonder, Heaven knows,
A decade is my limit, I'll admit;
(Two decades, if I like to use my toes
—Quite difficult, because I have to sit);
My memory store?—A signal's hardly writ
Before it starts to fade and disappear;
Gross errors, too, I frequently commit.
I'm only just a human engineer.

My maintenance is poor, I must disclose
One can't cure fibrillation or a fit
By ripping printed circuits out in rows,
And plug-in parts confer no benefit;
I've lots of foolish practices; to wit—
I'm fond of whisky..gin-and-tonic..beer;
(I'll have a quick one now, if you'll permit),
I am a thirsty human engineer.

Unlike computers, verse I can't compose
Nor counterpoint or harmonies emit;
For opera, or oratorios
My poor creative powers are quite unfit;
At noughts and crosses, children can outwit
My efforts; Draughts?—A schoolboy is my peer;
My chess?—They laugh until they nearly split.
I'm only just a human engineer.

L'ENVOI
Yet, Prince, there is one human perquisite;
When winking, with a Rabelaisian leer
At something no machine would term a Bit,
Thank Heavens I'm a human engineer!

Once again, critics can point out that this is not a true ballade, which has such a mathematical rigidity of form that not even G. K. Chesterton (a master of the ballade if ever there was one) could play about with it. The reason for this slight imperfection is that it was actually written by a computer. We couldn't really spare the time, and most computers will do almost anything for a pint of capacitor dielectric.

Tangent

Personal

L. Grainger.

J. H. N. Thompson.

R W. Rutherford.

C. Gresle Farthing.

Appointments

Mr. K. S. Phillips as sales controller of Research and Controls Instruments. He will also be responsible for the co-ordination of all sales staff activities.

Mr. W. D. Cartwright as field sales executive of Steels Engineering Products and **Mr. C. E. Drew** as an overseas sales executive.

Mr. C. J. Gallant as executive vice-president of North American Aviation. **Mr. G. B. Brophy, Mr. R. A. Lambeth, Mr. J. S. Smithson,** and **Mr. L. L. Waite,** as senior vice-presidents.

Mr. L. Grainger as head of the Metallurgy Division of A.E.A.'s research group at Harwell.

Dr. C. Starr as director of Atomic Industrial Forum.

Mr. R. Speller as manager, London sales division of Fielden Electronics. **Mr. F. G. Totty,** as north-eastern sales division manager and **Mr. F. B. Price** as manager of the Midlands sales division.

Admiral Sir Ralph A. B. Edwards to the board of Elliott Bros. (London).

Mr. G. P. Tinker (chairman), **Mr. J. C. Howard** (managing director), **Mr. F. S. Leigh** (assistant managing director), **Mr. D. L. Campbell, Mr. J. H. Crossley, Mr. P. F. Hancock, Mr. J. A. Monks** and **Mr. T. G. Tanner** to the board of the newly formed Birlec-Efco (Melting) company. Secretary of the company will be **Mr. J. C. Mantell.**

Mr. J. H. Morgan as head of the newly created cathodic protection department of Sturtevant Engineering.

Mr. V. M. Farrant as sales promotion manager, **Mr. P. M. Bartlett** as divisional sales manager, **Mr. J. A. Shelton** and **Mr. A. E. Deslandes** as technical liaison officers to Mervyn Instruments.

Sir Leslie Rowan and **Mr. R. P. H. Yapp** to the board of directors of Vickers.

Professor F. J. Dyson, Professor R. R. Wilson and **Dr. D. H. Gurinsky** to the research staff of General Atomic's John Jay Hopkins laboratory for Pure and Applied Science in San Diego, California.

Mr. W. E. Redfern to the board of English Steel Corporation.

Mr. R. E. Ginna as president of the High Temperature Reactor Development Associates.

Mr. E. Moriarty as chemical projects engineer of Vitro Engineering, New York.

Mr. W. Forbes Ritchie as manager of factory operations, Consolidated Pneumatic Tool.

Mr. P. A. J. Manley as assistant superintendent to A.E.I. turbine generator division.

Mr. R. W. Rutherford as chairman and **Mr. C. Gresle Farthing** and **Mr. J. H. N. Thompson** to the board of the newly formed Nuclear Chemical Plant. **Mr. C. J. Carter, Mr. C. Robson** and **Mr. N. H. Williams** as alternate directors; **Mr. R. Jowitt** as general manager and **Mr. E. J. G. Good** as secretary to the same company.

Mr. J. G. Wilson to the board of Universal Metal Products and **Mr. J. Kenyon** as general manager of the plastics division.

Lord Clydesmuir, Mr. J. A. Kilby and **Mr. T. J. Smith** to the board of Colvilles. **Mr. D. Ferguson** and **Mr. E. W. Ferguson** as special directors.

Mr. J. A. Black as president of the Steel and Engineering Industries Federation of South Africa.

Dr. F. K. Pittman as director of A.E.C. division of reactor development.

Mr. V. R. Prehn as deputy managing director, **Mr. E. R. Jones** and **Mr. C. T. Alderson** as assistant managing directors of Ruston and Hornsby.

Mr. R. D. Young and **Mr. A. J. S. Aston** to the board of directors of Tube Investments.

Mr. H. Morrogh as director of the British Cast Iron Research Association and **Dr. H. T. Angus** as deputy director.

Mr. H. V. Batchelor to the board of Weyburn Engineering.

Mr. J. S. Baillie as deputy chairman of Harland and Wolff. He will also continue to act as London manager.

Mr. William Fraser as managing director of Scottish Cables and **Mr. J. Ritchie** to the board.

Mr. A. Webber to the board of General Cable Manufacturing.

Mr. R. H. Atkinson as area director (Warwick) of Turriff Construction and **Mr. W. T. Barker** as area manager to the southern region.

Sir John Woods and **Mr. P. de Laszlo** to the board of Marconi International Marine Communications.

Colonel R. M. Percival to the board of Weardale Lead.

Mr. E. C. Shute as manager of the San Francisco Operations Office of A.E.C. **Dr. H. W. Newson, Dr. F. A. Gifford, Dr. L. Silverman** and **Dr. C. R. Williams** as additional members of the Advisory Committee on reactor safeguards.

Mr. K. Tardif as home sales manager, **Mr. H. Barker** as export sales manager and **Mr. H. F. Jones** as London area manager of G. A. Harvey.

Dr. P. Bowden to the board of English Electric.

Mr. S. C. Leslie as consultant on information policy for Associated Electrical Industries.

Mr. G. G. Gouriet to the board of Wayne Kerr Laboratories.

Mr. E. W. Stainton as assistant sales manager, switchgear dept.; **Mr. D. R. Clegg,** assistant sales manager, transformer dept.; **Mr. F. H. Davis,** assistant superintendent, foundries; **Mr. D. E. Thornhill,** assistant superintendent, transformer dept. Wythenshawe, **Mr. B. Dawkins** as assistant manager, education dept., Metropolitan-Vickers.

Mr. J. S. A. Bunting, divisional general manager, Cables Division; **Mr. W. G. Patterson,** divisional general manager, Telecommunications division. In January, 1960, **Mr. J. W. Ridgeway** will become divisional general manager of the Radio and Electronics division in Siemens Edison Swan's new long-term reorganization.

Sir Charles Westlake as chairman and **Mr. J. Black, Mr. H. Owen Houchen, Mr. J. O. Knowles** and **Mr. W. Padley** to the board of the newly formed Brookhirst Igranic company.

Dr. A. J. Kesterton as managing director of Davy British Oxygen, to become effective early in 1959.

Mr. L. M. T. Castle as managing director, finance and general administration, **Mr. R. Otley** as secretary, **Mr. G. H. T. Macleod** an assistant secretary and controller, general administration, and **Mr. T. W. Tomlinson** an assistant secretary of Stewarts and Lloyds.

Tours

Dr. J. N. Aldington, managing director of Siemens Edison Swan, recently returned from South and Central Africa. His main function was to be present at the official opening of a new factory at Springs, Transvaal, formed in conjunction with the Associated Telephone Co. The factory and firm will be known as the Telephone Manufacturing Co., of South Africa.

Awards

Professor George Charles de Hevesy, Hungarian-born chemist and teacher, the Atoms for Peace Award of $75,000 and a gold medallion. He was selected unanimously from a list of 111 nominations, representing 19 countries. Professor de Hevesy has previously won the Nobel Prize for chemistry, the Copley Medal of the Royal Society and the Faraday Medal.

Industrial Notes

General view of Laurence, Scott and Electromotors permanent exhibition at the company's Norwich works.

Nuclear Chemical Plant—the new company jointly formed by Power Gas Corporation, John Thompson and Humphreys and Glasgow—will be mainly concerned with the export of Atomic Energy Authority "know-how." The company will sell advice on all aspects of uranium production and refining, the re-processing of spent fuel elements and fission product recovery and plutonium separation. The company will also design, manufacture and erect chemical plant for these purposes together with equipment for the production of nuclear materials such as heavy water, beryllium and so on.

Contracts for the magnet power supply equipment for the 7,000 MeV proton synchrotron at the Rutherford high energy laboratory at Harwell were recently announced. British Brown, Boveri will supply the converter plant at a cost of over £500,000 whilst English Electric are to make rotating machinery worth £470,000. The converter plant includes excitrons, timing and control devices and transformers: Brown, Boveri have supplied similar equipment to CERN. English Electric will provide a 120 MVA power supply set comprising two alternators, two flywheels and two driving motors all coupled together on the same base.

American Nuclear Instrumentation. A new group has been formed within the Electronic Industries Association by manufacturers of nuclear instruments. Chairman will be Mr. N. Anton.

Permali have produced a film describing their modern factory at Gloucester and the latest techniques and equipment employed for producing densified wood laminates and high-voltage bushings.

Plessy Nucleonics are to supply the burst fuel element detection gear for the Swiss 10 MW heavy water testing reactor under construction near Zürich. Sequential sampling of the heavy water passing through the elements followed by scrubbing out of the gaseous fission products and proportional counting in a reciprocating rod precipitation chamber permits early detection of faulty elements.

Engineering, Marine, Welding and Nuclear Energy Exhibition will be held at Olympia, London, from April 16-30, 1959.

G.E.C.'s Atomic Energy Division has received an order for a power-operated manipulator from the industrial group of AEA. It is to form part of the expanding hot laboratory facilities at Windscale where its primary use will be the inspection of irradiated fuel elements including, eventually, those from the commercial power stations at present under construction.

Avo, manufacturers of electrical, electronic and nucleonic instruments, have bought the entire share capital of Taylor Electrical Instruments of Slough.

Martonair have opened new offices at the Central Administration Building, Team Valley, Gateshead, 11, and a new showroom and offices at 46 Great Hampton Street, Birmingham.

Head Wrightson have recently completed a new heavy plate shop in their Thornaby-on-Tees works. The shop is situated in the centre of the works and is connected by rail tracks with the other production shops and the main-line station.

Rocol manufacturers of molybdenum disulphide and other industrial lubricants, are building a new 16,000 sq. ft factory near Leeds.

20th Century Electronics have contracted to supply reactor ionization chambers and fission chambers for the Belgian reactor experiments. The ionization chambers are type RC6 which contain enriched boron coatings and incorporate a high degree of compensation against γ radiation.

Evershed and Vignoles have opened a new district office at 14 Yarm Lane, Stockton-on-Tees. Tel. Stockton 64288.

Dryer and Gas Plant Division has been created by **Birlec** to handle adsorption plant and gas generators.

Wolf Electric Tools have recently registered a new company, **Ralliwolf Private, Ltd.,** with a freehold site at Mulund, near Bombay, in India. The factory is expected to be completed by mid-1959.

Marconi Instruments will hold a private exhibition of their telecommunication measurement equipment at the Waldorf Hotel, London, on January 19-24.

Anti-Dust Services have opened an office at 27 Eastern Avenue, Wanstead, E.11. Tel. Wan 3467.

Vitro Laboratories have been awarded contracts to investigate the chemistry of long-lived radioactive fission products by the Atomic Energy division of **Phillips Petroleum.** The main object is to develop safe and effective storage methods for hot fission products resulting from the burn-up of nuclear fuels.

Manchester University is to appoint a Professor of Nuclear Engineering. The chair, which is worth at least £2,300 per year, is being offered by the Department of Engineering, Faculty of Science.

University of Nottingham will hold a series of lectures on modern developments in engineering design on February 5, 12, 19 and 26, at the Lecture Hall, Portland Buildings, Nottingham.

Hayward Tyler are to supply high pressure glandless motor pumps for the new base load power stations to be built for the C.E.G.B. at Thorpe Marsh and Blyth. They will be used for forced circulation of the boiler water through the water tube system.

The Census of Production for 1959 will cover the industries in Orders II-XVIII of the new edition of the Standard Industrial Classification, viz: mining and quarrying, manufacturing, construction, and the gas, electricity and water supply industries. Questions asked will cover the following three items only: (a) total value of goods sold and work done; (b) stocks; (c) capital expenditure.

Applications for the CIBA Fellowship should be submitted by January 31, 1959, for the academic year 1959-1960. Address is CIBA Fellowship Trust, CIBA (A.R.L.), Ltd., Duxford, Cambridge.

Nuclear Engineering Ltd. have built a new irradiation unit which utilizes high energy gamma rays from cobalt 60 to initiate or control certain chemical reactions. It is for export to Germany.

The new Customs Tariff, based on internationally agreed classifications and known as the Brussels Nomenclature, has been published for H.M. Customs and Excise by H.M.S.O.. It will come into operation on January 1.

Alco Products of New York has inaugurated a campaign to sell its 2 MW skid-mounted portable reactor plants to utility companies for training and research.

Great Lakes Carbon International have been appointed sales representatives for all commercial products of the new Anglo Great Lakes Corporation graphite plant at Newcastle-on-Tyne.

Hill and Smith have been appointed structural steelwork contractors at Harwell for the next two years by the U.K.A.E.A.

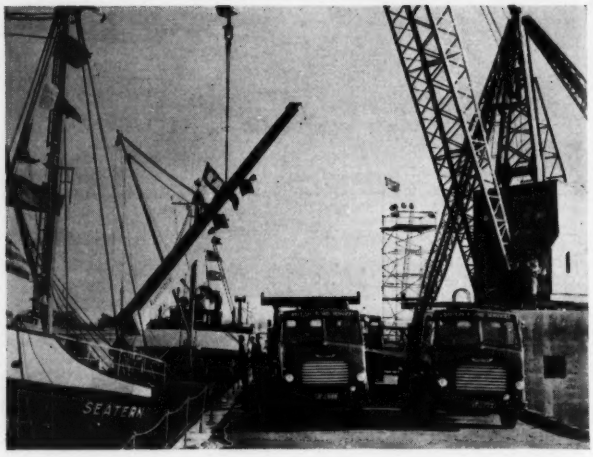
Laurence, Scott and Electromotors have set aside a section of their works at Norwich for a new permanent exhibition of electrical equipment.

Pye have been awarded a contract by the Nuclear Power Plant Company to supply television equipment to the Italian nuclear power plant at Latina.

The Institution of Electrical Engineers will hold a convention on thermonuclear process in London on April 29 and 30, 1959. Probable topics to be discussed will be: basic principles of thermonuclear processes, prototype British experiments, i.e., Zeta I, Sceptre III and the Linear Pinch, and possibilities of direct conversion from nuclear to electrical energy. Reviews of related work in the U.S.A. and U.S.S.R. will also be included.

British Insulated Callender's Cables have offered to acquire the entire share capital of the **Telegraph and Construction Co., Ltd.,** on an exchange of shares basis.

Magnesium fluoride slag containing small amounts of normal uranium is for sale by the AEC at $26 per kilogram of contained uranium in the slag. The material contains about 3% uranium.



One of the leg sections of the Goliath crane for Hinkley Point was recently shipped by Babcock and Wilcox from Renfrew to Combwich. In the next two years some 30,000 tons of equipment will be shipped to the new port facilities at Combwich, a few miles from the Hinkley Point site.

Catalogues

F. H. Lloyd have recently produced a fully illustrated brochure describing their James Bridge Steelworks. Methods of quality control, together with planning organization and the machining facilities available, are discussed. (Victoria Mansions, 28 Victoria Street, London, W.1.)

The Magnesium Industry Council have published an attractive booklet dealing with the properties and uses of magnesium and its alloys and stressing the growing importance of magnesium alloys in the engineering industry. (Dickens House, 15 Took's Court, London, E.C.4.)

British Institution of Radio Engineers have published selected abstracts from their house journal covering the period 1946 to 1958. (9 Bedford Square, London, W.C.1.)

Johnson, Matthey and Co. have produced a new publication, 1700-Platinum Laboratory Apparatus, surveying the platinum laboratory apparatus and electrodes in their range. (73 Hatton Garden, London, E.C.1.)

Palmer Aero Products have brought out a brochure on the application of non-destructive testing to industry by X-ray and gamma ray. (Penfold Street, Edgware Road, London, N.W.8.)

The Aluminium Courier, published by the Aluminium Development Association, includes a comprehensive review of the rôle played by aluminium in nuclear engineering, in its September issue. The article is well illustrated and a separate section with tabulations discusses the nuclear properties of aluminium. (33 Grosvenor Street, London, W.1.)

John Laing and Son review the work of the company over the past year in an attractive 32-page publication. The overseas contract work and the part played in nuclear power engineering in the U.K. are well illustrated. (London, N.W.7.)

Williams and James, manufacturers of compressed air and vacuum equipment have listed their products in a well-bound catalogue. (Gloucester, England.)

Nuclear-Chicago describe a new inherently safe, subcritical reactor for training purposes for colleges and universities, in their news-sheet, *The Nucleon*. In a different edition, details of a Dynacon electrometer and Model 1820 recording spectrometer, are given. (223 West Erle Street, Chicago 10, U.S.A.)

Ferranti have produced an attractive booklet on their Perseus data-processing system. The order code is listed in the conclusion. (Kern House, 36 Kingsway, London, W.C.2.)

100 A1, a bulletin published by Lloyd's Register of Shipping, summarizes events up to the present moment and the work of the special Land Division, established in 1956, to handle nuclear power plant contracts and non-marine work, in a four-page article.

In an electronics and automation survey *The Financial Times* presents a complete picture of the progress and implication on industry in general and includes an article on nuclear power stations with regard to automatic control, by Mr. M. V. Needham.

Meetings

January 6—Institution of Electrical Engineers (Engineers' Club, 17 Albert Square, Manchester). "Design of Electro-Mechanical Auxiliaries directly associated with Power-Producing Reactors," A. E. Harwood, P. Scott and B. H. Stonehouse.

January 6—Institution of Electrical Engineers (Carlton Hotel, North Bridge, Edinburgh). "Electrical Installation at Calder Hall Nuclear Power Station," N. J. Mackay and E. Hardwick.

January 6—Institution of Electrical Engineers (North Midlands Centre, C.E.G.B. Offices, Leeds). "Standardization of Control Facilties for the British Grid: Communications, Indications and Telemetering," P. F. Gunning.

January 6—Institution of Chemical Engineers (The Geological Society, Burlington House, W.1). "Feed water and boiler water standards in the Central Electricity Generating Board," R. L. Rees and F. J. R. Taylor. "The treatment of water for an industrial high pressure boiler plant," J. Arthurs, J. A. Robins and T. B. Whitefoot.

January 7—Institute of Marine Engineers (Birmingham Exchange and Engineering Centre, Stephenson Place, Birmingham). "Nuclear Steam Propulsion for Merchant Ships," by W. R. Wootton.

January 7—Institution of Electrical Engineers (C.E.G.B. Offices, 111 High Street, Portsmouth). "Ultrasonics in Industry," C. F. Brockelsby.

January 7—Institution of Electrical Engineers (Cleveland Scientific and Technical Institute, Corporation Road, Middlesbrough). "ZETA—The Engineering Aspects of the British-controlled Thermonuclear Reaction Experiments," R. Carruthers.

January 12—British Institution of Radio Engineers (North Eastern Section, Institution of Mining and Mechanical Engineers, Neville Hall, Westgate Road, Newcastle upon Tyne). "The Design and Construction of an Electronic Digital Computer," R. W. Walker.

January 15—Institution of Electrical Engineers (in conjunction with the British Nuclear Energy Conference). "Electrical Installation at Calder Hall Nuclear Power Station," N. J. Mackay and E. Hardwick.

January 16—Institution of Electrical Engineers (Technical College, Stoke-on-Trent). "Operational Experience at Calder Hall," K. L. Stretch.

January 19—Institution of Electrical Engineers (South Wales Institute of Engineers, Park Place, Cardiff). "The Future Pattern of Nuclear Electricity Power Stations," I. Everson.

January 20—Institution of Electrical Engineers (Engineers' Club, 17 Albert Square, Manchester). "The Atomic Clock," L. Essen.

January 20—Institution of Chemical Engineers (North Western Branch, The Blossoms Hotel, Chester). "Separation of isotopes by molecular distillation," P. T. Nettley.

January 20—Institution of Electrical Engineers. Discussion on "D.C. Amplifiers." (Opened by K. Kandiah.)

January 22—Institution of Electrical Engineers (Grand Hotel, Sheffield). Informal Lecture, Sir Christopher Hinton.

January 22-23—The Institute of Physics (Institution of Civil Engineers). Symposium on "Nuclear fuel cycles."

January 26-27—Society of Instrument Technology (Mansion House, Portland Place, London, W.1, 5.30 p.m.). Symposium on Flow Measurement.

January 26—Institution of Electrical Engineers (Royal Festival Hall, London). Faraday Lecture on "Automation," H. A. Thomas. (Admission by ticket available during December from the Institution on receipt of a stamped addressed envelope.)

January 28—Institution of Electrical Engineers. "Electrical Installation at Calder Hall Nuclear Power Station," N. J. Mackay and E. Hardwick. (Rugby College of Technology and Arts.)

January 28—Institute of Welding, N.L. Branch (54 Princes Gate, London, S.W.7). "Materials and Fabrication Problems in Reactor Technology," A. Prince.

January 28—Institution of Electrical Engineers (in conjunction with the British Nuclear Energy Conference). "Design of Electro-Mechanical Auxiliaries directly associated with Power-Producing Reactors," A. E. Harwood, P. Scott and B. H. Stonehouse.

Processes and Equipment

For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.

Developments at E.M.I.

Recent additions to the series of photo-multipliers made by E.M.I. Electronics include replacement parts for standard American tubes, which still use the venetian-blind system, the number of stages being adjusted to conform with the U.S. tube characteristics. A new large-diameter tube has also been introduced into their existing range, with a 250 mm diameter flat cathode feeding a standard dynode system.

A new photo-cell, type 25110, constructed in a sodaglass envelope on a B9G base is likely to cause interest, with a sensitivity of 30 mAmp/lumen to tungsten light and a dark current of only 10^{-13} Amp. Perhaps the most fascinating exhibit was a piece of silver foil 0.0002 in. thick, with a transparency of 65% and a tolerance on this transparency of only $\pm 2\%$ over its area. The foil is perforated by a pattern of holes, the mesh of which can be pre-set in the range 600-1,000 per in.

The Emiac-2, E.M.I.'s general-purpose analogue computer, has already been mentioned in these pages, but an application of this computer of some novelty was recently described. This concerned the setting-up of an analogue of a chemical plant under construction in the north of England which allowed not only faults in the design to be revealed, but allowed complete programming of the commissioning, and a complete evaluation of the flow pattern of the system and defining of the stable conditions; subsequent plant experience has shown the forecasts of the computer to be consistently accurate. This application of computer technology to chemical engineering is likely to increase considerably in the coming years.

(E.M.I. Electronics, Ltd., Hayes, Middlesex.)

1157

New Multi-point Recorder

A multi-point recorder which provides a permanent printed record of variable inputs from any one of 500 points, the time at which the measurement was taken and the channel identification, is being produced by Savage and Parsons.

The recorder consists of a main unit, and from one to ten extension units coupled to it through a junction box. The main unit contains the printing mechanism which is mechanically coupled to a motor-driven slide-wire potentiometer, a high gain amplifier for the control of the motor and servo system, a precision voltage supply for the comparing with thermocouple and other d.c. inputs, and associated power supplies. Three types of extension unit are available —one for strain work, one for thermocouple inputs and one for straightforward d.c. inputs.

(Savage and Parsons, Ltd., Watford, Herts.)

1158

Handling Isotopes

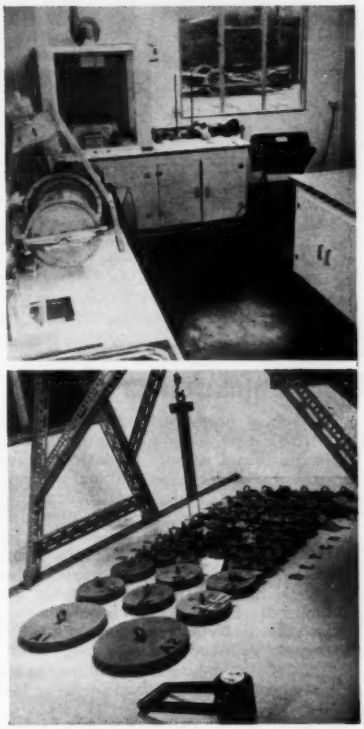
A new laboratory to provide safe storage and loading facilities for radio-active sources used in connection with industrial nucleonic instruments has been built by Isotope Developments at Aldermaston Wharf, near Reading. The sources are normally sealed and tested for leakage by the suppliers (A.E.A.) and the danger of contamination by radio-active material from them is relatively small, but every precaution has been taken to ensure maximum safety. Tracer experiments involving small quantities of open sources in the form of liquids or powder are also undertaken. The resultant dangers from a spill have been well catered for, however, by using material which can be easily decontaminated in the construction of the laboratory. The floor is covered with semi-tropical asphalt with a non-absorbent surface and the walls and ceiling are lined with plaster board to give a ledge-free surface, which is painted with a special, chlorinated rubber paint. All working surfaces are covered in plastic materials.

Protective measures in the store-room for radioactive material include a concrete storage block for gamma sources, a bay shielded with inter-locking concrete blocks for loaded gamma source units, and a steel cabinet for the storage of beta sources. The laboratory proper contains a concrete and lead loading cell for gamma sources, a Perspex shield for loading beta sources, and a fume cupboard.

Records of the nature, activity and location of all sources on the premises are kept in a normal system of stock control and when dispatch is effected to a factory, the information is passed on to H.M. Factory Inspectorate so that the presence of a radio-active source in a factory is known to them.

(Isotope Developments, Ltd., Beenham Grange, Aldermaston Wharf, nr. Reading, Berks.)

1159



Part of Isotope Developments' new laboratory facilities. The lower picture shows the dense barytes concrete storage block for gamma sources.

Advanced Heat Treatment Unit

A central heat treatment plant is now in full operation at the Darley Dale works of Firth-Derihon Stampings. The new equipment, which incorporates many advanced ideas, consists of three dual-system heat treatment furnaces, two tempering furnaces, an oil quenching machine, turntable furnace charger, loading and cooling tables and an instrument control room. All the furnaces are 11 ft long, 6 ft 6 in. wide with a height of 3 ft 3 in. to the spring line of the arch in the doorway. Loads of up to 5 tons can be handled. The whole installation has been designed to deal with large or small batch production efficiently and to eliminate manual handling.

(The Firth-Derihon Stampings, Ltd., Sheffield Road, Tinsley, Sheffield, 9.)

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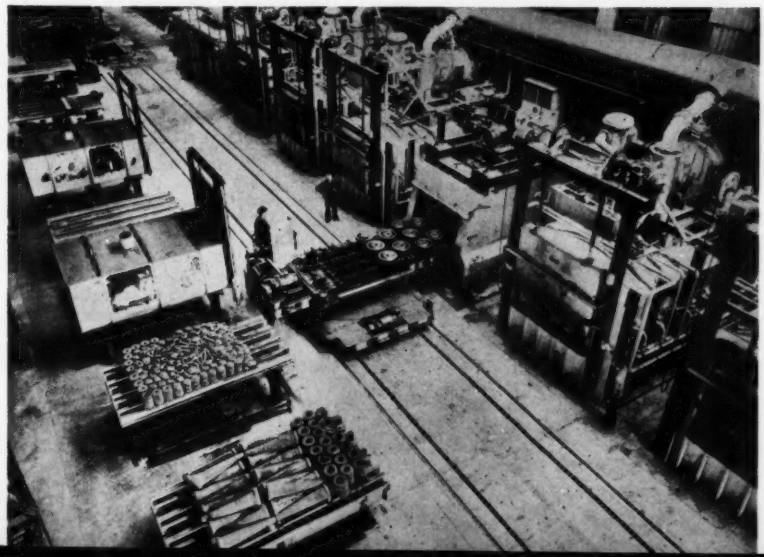

General layout of Firth-Derihon's new heat treatment plant at the Darley Dale works. The furnaces were supplied by Gibbons Bros.

Data Processing and Information System

Panellit (a member of the Elliott-Automation Group) have just completed a new design of data processing and information system to the instructions of the United Kingdom Atomic Energy Authority for reactor operation. The system is to be installed at Calder Hall. The equipment is similar in conception to the Panellit 609 system which employs an Elliott 802 Computer. In this application it is required to scan at high speed 600 points measured by thermocouples to detect variation in temperature level and rates of change of temperature. A requirement of the U.K.A.E.A. was that the design should embrace all techniques which would ensure maximum on-line availability: to this end the design incorporates many unique features.

The only moving parts in the entire system (excluding the output printer) are the input relays which connect the selected thermocouples. After investigation the Clare Mercury-wetted relay was selected as possessing absolute reliability. These relays have been tested to 3×10^9 operation without failure and have a minimum of "noise," a factor essential in a system capable of a high degree of discrimination. The input signals for the thermocouples are fed to a high stability Offner differentially-connected amplifier and from this point to an electronic analogue to digital converter before being passed into the computer.

The Elliott 802 which forms the heart of the system is a fully-automatic stored programme electronic digital computer. Reliability has been achieved by careful design and the use of solid state devices. The memory store consists of a matrix of magnetic cores and cores are also used, in conjunction with transistors, to form the basic logical elements in the machine.

The programme of the machine is fed in automatically by a punched tape reader: if at any time a complete change is required an entirely new programme can be fed into the computer in one minute. Where only individual points have to be changed a simple manual means is available.

For reactor application the facilities in certain parts of the equipment have been duplicated in the interest of operational availability. A comprehensive self checking system at the end of each scan automatically changes over to the alternative duplicate section to ensure continuous operation. At the same time a warning is given that part of the machine has not satisfied the built-in checking system.

Output from the machine is recorded on both automatic typewriters and a strip printer. Two IBM typewriters operate concurrently to display temperatures in groups associated with the grouping of measurement points. Alarms as they occur are immediately printed on the strip printer. Full manual demand facilities are available for instant display of information. To allow any point to be recorded in analogue form on potentiometric recorders a jack panel has been included enabling any 12 points to be connected to the recorders. The equipment has been designed to provide a complete record of 600 points scanned in two minutes for both level and rate of change: the facilities include a history of the last five scanning operations.

(Panellit Ltd., 70 Dudden Hill Lane, N.W.10.)

1160

Recombination of Oxygen and Deuterium in DIDO

The use of heavy water in a reactor of the DIDO type involves the problem of radiolytic gas—a mixture of deuterium and oxygen produced by the splitting of heavy water molecules under the influence of irradiation. This gas cannot be allowed to accumulate in the sealed reactor system or a serious build-up of a highly explosive gas mixture would occur; a further and economic consideration requires that the decomposed heavy water, being an expensive commodity, is recombined and returned to the system with the minimum loss.

In DIDO the radiolytic gas diffuses at the rate of about 1 cu. ft per hour to the surface of the heavy water, where it is picked up and swept out of the reactor in a stream of helium. A proportion of this gas mixture is continuously circulated over a recombination catalyst when the deuterium and oxygen are reformed to yield heavy water vapour, which is subsequently returned to the reactor. The recombination unit is heated to prevent the condensation of D_2O on the catalyst.

The recombination equipment for DIDO is from the range of Deoxo catalytic recombiners developed and manufactured by Engelhard Industries. The unit provides for the continuous removal of oxygen from hydrogen or certain other gases by promoting the reaction with hydrogen to yield water vapour, and will operate at room temperature or higher; the efficiency of the catalyst is such that molecular oxygen concentrations are reduced to well below 1 v.p.m. over the catalyst.

Although, theoretically, the DIDO reactor should produce radiolytic gas with the oxygen and deuterium in stoichiometric relationship, in practice it has been found that the oxygen content is always low. This loss of oxygen is attributed to oxide formation on metal surfaces in the system and support is given to this theory by the observation that oxygen losses have decreased during the period that DIDO has been in operation. However, the oxygen loss is significant and steps have to be taken to make up the deficiency from an external source which naturally has to be free from hydrogen, otherwise the subsequent recombination in the system would lead to the production of light water. The removal of hydrogen prior to the injection of the oxygen into the system may be readily carried out by the use of another type of Deoxo purifier; here again the product of the catalytic reaction is water vapour which may be easily removed from the oxygen by desiccants. The injection of the requisite oxygen is carried out on the DIDO reactor at intervals of to two-three months when the deuterium level has risen to some 3-4,000 p.p.m.

The oxygen content of the helium stream is monitored both before and after the Deoxo recombiner; the downstream content is checked continuously and the upstream oxygen, which normally runs at around 350-500 v.p.m., is checked every eight hours. In addition to oxygen the upstream deuterium content is also monitored. All of these critical measurements are accurately and conveniently carried out by means of the Deoxo indicator.

The successful application on DIDO of these various Deoxo products to the new problem of radiolytic gas production was undertaken in conjunction with the Reactor Services Section of the Industrial Chemistry Group at A.E.R.E., Harwell.

For power reactors, particularly those of the boiling water type, there has arisen the need for a recombination catalyst to operate in steam at high temperature and pressure. As conventional recombination catalysts will not withstand these severe conditions for any length of time a specially modified type must be employed. To meet this requirement the Research Division of Engelhard Industries has recently introduced a new platinum group metal catalyst capable of effecting recombination in steam at high pressures and temperatures; the support material employed in this catalyst is particularly resistant to breakdown under these conditions.

(Engelhard Industries, Ltd., Baker Platinum Division, 52 High Holborn, London, W.C.1.)

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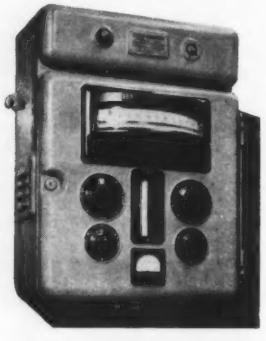
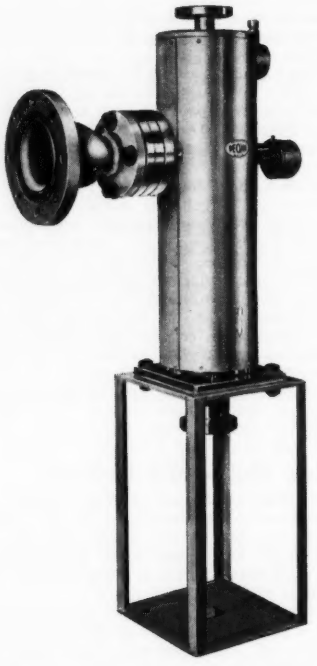


Deoxo unit for measuring oxygen content.



Recombination unit made by Engelhard Industries.

A New Metrovac Diffusion Pump

The latest Metrovac diffusion pump, the 9/14, has been designed primarily to give its highest pumping speeds at the lower pressures; it is thus very suitable for the large vacuum systems used in nuclear physics research. This pump did in fact form the basis of the high vacuum system supplied by Metropolitan-Vickers for the evacuation of the ZETA torus. Both oil and mercury versions of the pump are available.

The characteristics of the pump are those of a 14-in. diameter pump at pressures below 5×10^{-4} mm Hg, and of a 9-in. diameter pump at higher pressures (of the order of 10^{-3} mm Hg), but with a power consumption of only 2.5 kW for the oil pump and 3 kW for the mercury pump.

The peak, unbaffled air capacity of the oil pump is 2,850 litres per second, which, it is claimed, is a far higher speed than that attained by conventional pumps with the same power consumption.

(Metropolitan Vickers Electrical Co., Ltd., Trafford Park, Manchester, 17.)

1162

Test Windings for Accelerator

Specialized facilities for prototype and "one-off" production at the Horsham works of H. and E. Lintott are frequently employed by A.E.R.E., Harwell, for experimental work.

Towards the end of 1957 the company was asked to undertake the manufacture of test windings in connection with the installation of the 7 GeV proton synchrotron for N.I.R.N.S., Harwell. The equipment was required for certain test procedures necessary in determining the magnetic flux in the laminated steel blocks which form the magnet proper. The windings comprised an aluminium conductor 1.37 in. by .87 in. with a ½-in. bore arranged in the form of four double layers or pancakes, each of 20 turns with a cross-over in the centre.

To facilitate handling, the company first constructed special spools, which were supplied to the aluminium extruders, the length of material per extrusion being approximately 600 ft. As the size of the winding was approximately 6 ft by 5 ft, with an 18-in. off-set at one end, and as the weight per winding was around 28 cwt, it was also necessary to make special jigs and fixtures to support the load involved and to enable the very close dimensional accuracy required to be maintained.

(H. and E. Lintott, Ltd., Horsham, Sussex.)

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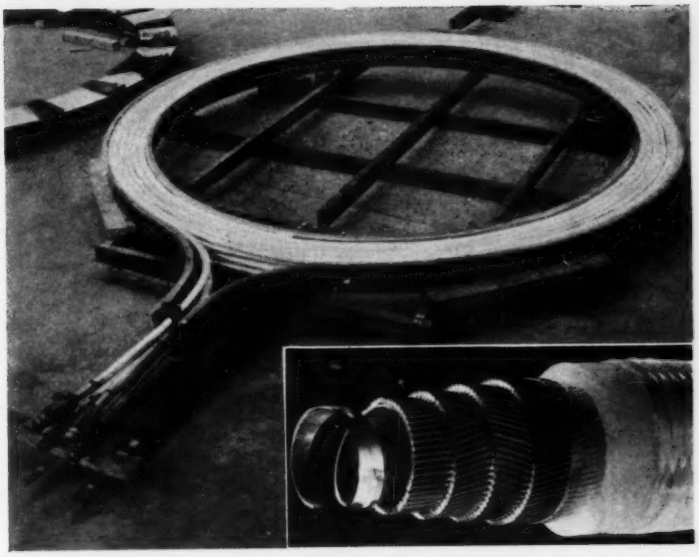

Water-cooled cable for installation in the Glasgow University synchrotron. Inset, construction of the hollow conductor.

Water-cooled Cable

Siemens Edison Swan have developed a water-cooled cable of high current rating. Of single-core construction it consists of four layers of wire stranded around a central spiral which forms the passage for the water. It is insulated by polythene with a conductor cross-section of ½ sq. in. and is intended for currents of up to 1,600 amp operating at 8-10 kV. The uses envisaged include generator transformer units, normal distribution systems and thermo-nuclear power. It has already been put into operation at the 450 MeV synchrotron at Glasgow University and is being supplied to Harwell for use in ZETA.

(Siemens Edison Swan, Ltd., 155 Charing Cross Road, London, W.C.2.)

1164

Beryllium Tubes

Recent work at Tube Investments Technological Centre at Walsall has been concerned with the fabrication of beryllium. In a series of tests the laboratory has produced tube of 0.3-in. bore with a wall thickness of 0.04 in. in lengths of 2 to 3 ft. A very thin walled tube with a diameter of 0.7 in. and a wall thickness of 0.012 in. has also been made. Beryllium tubes of 8 to 10 ft long with a wall thickness of 0.08 in. and a diameter of 0.5 in. upwards, together with random lengths of wire and rod are amongst other examples of progress in fabrication. More recently the laboratory has been bending small-bore beryllium tube.

(Tube Investments Technological Centre, Walsall, Staffs.)

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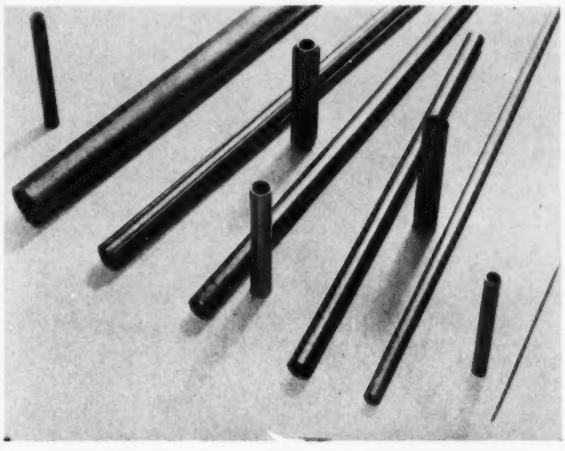

Beryllium tubes, rod and wire fabricated by Tube Investments Technological Centre. Left to right ½ in. dia. rod; 1½ in. by 1 in. bore tube; ¾ in. by .45 in. bore finned tube; .67 in. by .45 in. bore tube; .7 in. O.D. by .012 thick tube; .07 in. dia. wire. The tubes were not machined after processing.

Briefly . . .

Pressed-steel pans for storage of small parts in extensive use at A.E.A. establishments are made by Welconstruct Co., Ltd., of Martineau Street, Birmingham, 2. The 642-series pans are each 6 in. by 4 in. by 2 in. in 24 g.

1166

New d.c. permanent magnet motor, PMIC, by R. B. Pullin and Co., Ltd., Great West Road, Brentford, Middx., has a rated output of 80 g, cm at 5,000 r.p.m.

1167

Epiglo C, an epoxy-based heavy duty plastics coating, has been introduced by Corrosion Ltd., of Southampton. Epiglo C is applied by normal paint techniques. It has already been used to protect the exterior of tankers carrying caustic soda and also hydrofluoric acid.

1168

Mirotilt probes, 12 in. and 24 in. long, by Engineering Developments Ltd., Mark Road, Hemel Hempstead, Herts, facilitate the internal inspection of tubes and similar hollow objects. The company's Probe-Lite provides an 8x magnification for examination of external surfaces.

1169

High-strength vanadium alloys have recently been developed by the Armour Research Foundation. The alloys contain 50% titanium by weight together with varying amounts of aluminium, chromium and silicon.

1170

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 791,845. Device for sampling gases. To: Atomic Energy of Canada Ltd. (U.S.A.).

An aerosol sampling device based on the impaction principle. The detection of alpha-emitting materials in the form of aerosols is difficult, because the activities to be measured are very low, and natural radon decay products may completely mask that due to concentrations of more toxic contaminants. It has been noted that radon decay products are preferentially associated with smaller dust particles; 90% of radon decay produces activity on particles of less than 0.035 microns dia. On the other hand, if material is rendered airborne by mechanical disruption, the bulk of the material is in the larger particle sizes, with only a very small fraction of the mass in sizes of less than 1 micron dia. By separating airborne particles into two groups, greater and less than 1 micron dia., samples of active dust from escapes or spills in industrial and laboratory processes can be obtained free from radon decay products. Available devices effecting separation of this kind have a sampling rate of about 20 l/min. Rapid detection, however, e.g., of airborne plutonium or other alpha- and beta-gamma-active materials require a rate of 400-1,000 litres per minute. The device achieves this result by lightly drawing air (by a conventional vacuum cleaner blower) through a jet arrangement against a greased tray at the end of the suction tube, where the very fine particles collect on the tray, and can be examined after a few minutes with an alpha-sensitive scintillation counter.

B.P. 795,596. Nuclear reactions. T. Volochine (Belgium).

Refers to a fusion-type reaction with a substantial release of power. The probability figures for effective encounters and fusion reactions between nucleons, and between nucleons and atomic nuclei can be increased by so arranging matters that the reagent particles are all presented to the reaction area under such conditions that their magnetic moments are so related as to contribute to bringing the particles towards one another. These conditions can be brought about by subjecting both reagent parts to a polarizing magnetic field, so directed in each case that it aids the encounter fusion of the individual particles. The precise field and the optimum paths are to be predetermined in accordance with the nature and characteristics of the particular nucleus to be produced, specifically with the values of the magnetic moment and spin thereof. Certain stability conditions have also to be taken into account and the internal structure of the reagent. Any means may be used to create the desired polarizing field such as solenoids, magnetic fields, etc.

B.P. 795,766. Ion sources. M. von Ardenne (Germany).

In mass spectrographs and magnetic isotope separators certain properties are desirable such as high emission density in the ion emission aperture; high plasma stability; high commercial efficiency (over 10%); uniform emission characteristics and small dispersion of the initial velocity of the ions; (for magnetic isotope separators) a large emitting area, if possible, slit-shaped; small beam aperture in the plane at right angles to the direction of the separating magnetic field; a very small beam aperture in the plane parallel to this direction; further, a convergence should be given to the ion beam in the plane parallel to the direction of the magnetic field with a beam cross-over in its central zone; no auxiliary magnetic field should be required. This is achieved by the arrangement of an intermediate electrode disposed between anode and cathode of an ion source in which a low-pressure gas discharge is effected which is constricted by an aperture in the intermediate electrode. The anode region of the plasma produced by the discharge is to be situated directly in front of an ion emission aperture of the anode. The (externally situated) ion source is combined with a magnetic isotope separator with a magnetic field extending over a sector of 90 to 60 deg.

B.P. 795,826. Nuclear reactors. D. W. T. Angwin. To: General Electric Co., Ltd.

The design of pressure vessels for gas-cooled nuclear reactors with conventional materials leads to certain difficulties (e.g., pressure resistance at reasonable wall thickness; assembly; construction on site). These difficulties can be reduced by constructing the vessel of concrete lined with refractory material impervious to gas. The lining may be a thin metallic skin of a refractory nature (series of flanged steel plates bolted or clamped together during casting of the concrete, afterwards welded to ensure leak-proof assembly) or the concrete may be provided with a ceramic flux coating fused in position and forming a hard-glazed diffusion barrier. The concrete pressure vessel may serve as the whole or as part of the radiation shield. It is also possible to construct the vessel of an inner part of refractory concrete and an outer part of ordinary concrete, and to apply the construction to a reactor as described in B.P. No. 785,945, with a double-shelled pressure vessel, in which case the outer shell would be constructed of concrete with a thin metallic or other lining.

B.P. 795,920. Production of heavy water. To: U.K. Atomic Energy Authority (U.S.A.).

Steam is reduced in a fluidized mixture with a finely divided reducing material (iron or iron monoxide) at high pressures (up to 1,100 atm) and temperatures (650-900°C). The mixture of deuterium and hydrogen is then separated from the reducing material and brought into reaction with liquid water under full pressure of hydrogen production, so that part of the hydrogen is replaced by deuterium. The hydrogen and any residual deuterium are then separated from the water of increased D_2O content, which is withdrawn and recycled. D_2O occurs in natural water in a concentration of 1 to 6,000 and by the new process may be concentrated to between one and 10%. For further concentration other methods are preferable.

B.P. 796,187. Moisture proofing of luminescent thallium-activated sodium iodide. E. K. Cole, Ltd., M. J. Toogood.

Any superficial moisture is removed and a coating of an epoxy resin applied which is then cured. The product may be used without a metal container.

B.P. 796,239. Dosimeter for evaluating the dosage of penetrating radiation. To: General Aniline and Film Corp. (U.S.A.).

A casing opaque to actinic light (aluminium or polymethyl-methacrylate or polystyrene) has a gamma ray intensifier screen in an opening and a modulating wedge with steps of increasing densities in contact with it adjacent to a light sensitive element with a high-speed print-out emulsion. The casing can be closed and the emulsion side of the photographic element raised (rotated) and viewed through a window with filter. The wedge bears characters which become visible as white dots the number of which corresponds to the intensity of the radiation. Post-exposure may be effected.

B.P. 796,589. Process for production of uranium. To: U.K. Atomic Energy Authority (U.S.A.).

It has been found that close control of the particle size of the uranium tetrafluoride is important in obtaining massive uranium in relatively high yields. The particle size should preferably be such that 90% passes a 60 mesh sieve; 85% an 80 mesh; 75% a 100 mesh; 50% a 200 mesh sieve. The excess granular calcium used for the reduction at elevated temperature has a particle size not greater than 7 mesh. Very fine calcium should be present for initiating the reaction. The calcium tends to vaporize and intimately mix with the uranium tetrafluoride. Yields range from 80% to 95% of the theoretical yield.

B.P. 796,926. Gas lubricated bearings. A. G. Montgomery, F. Sterry. To: U.K. Atomic Energy Authority.

When using gas lubricated bearings, instability of the rotor occurs under certain conditions, and may develop into violent back and forth movements of the rotor across a diameter of the bearing (as an oscillating piston in a double-ended cylinder). An incipient oscillation is also present determined by the mass of the rotor and the load/displacement characteristic of the bearing. The clearance between rotor and bearing shell is of importance for this oscillation and, therefore, has to be kept extremely small (0.0005 in.) and only very small tolerances are thus permissible. This clearance, however, can be raised to the order of 0.003 in. for an 0.75 in. rotor diameter by arranging the bearing sleeve in a resilient mounting, preferably as a porous metal sleeve surrounded by two rubber rings at each end which also act as gas seals in an annular chamber under gas pressure around the sleeve.

B.P. 796,966. Nuclear reactors. H. Chilton. To: C. A. Parsons and Co., Ltd.

In boiling water reactors, circulation of the water requires large pumps and large ducts passing through the walls of the reactor vessel. To avoid this, use can be made of natural circulation, induced by the difference in density between the water in the space between the fuel duct and the vessel walls and the water-steam mixture in the fuel ducts. The rate of circulation is limited by the available head but can be assisted by making use of an injector effect. Nozzles are arranged at the inlets of the fuel ducts and water withdrawn from the vessel and pumped through these nozzles at high velocity produces this effect and assists the natural circulation. Feedwater can be used, instead of withdrawing water from the vessel, for supplying the nozzles.